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Aberdeen Proving Ground,
Maryland

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Submitted to:

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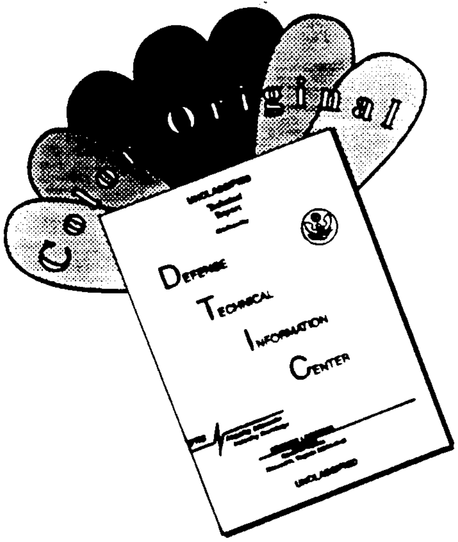
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13. Abstract

This report presents the results of the Feasibility Study (FS) performed for the Explosive Washout Lagoon Ground Water of Umatilla Depot Activity (UMDA) near Hermiston, Oregon.

UDMA is a U.S. Army ordnance depot located near Hermiston, Oregon. From the mid-1950s to 1965, explosives, contaminated sludges, and liquid wastes generated at the UMDA Washout Plan were discharged and allowed to collect and infiltrate into the soil at the Explosive Washout Lagoons. Explosives contamination of the soils and ground water led to its inclusion on the National Priorities List by EPA.

The FS addresses the contamination of ground water at the Explosive Washout Lagoons; develops objectives for ground water remediation; and identifies, develops, screens, and evaluates ground water remedial action alternatives.

Basic components of the remedial alternatives subjected to a detailed evaluation for the contaminated ground water at the Explosive Washout Lagoons include: No Action; Institutional Controls; Treatment of the ground water by UV/Oxidation until the aquifer meets the preliminary remediation goals; Treatment of the ground water by Granular Activated Carbon (GAC) until the aquifer meets the preliminary remediation goals; Treatment of the ground water by UV/Oxidation until the aquifer meets a carcinogenic risk of 10^{-4} and a hazard index of 1; and Treatment of the ground water by GAC until the aquifer meets a carcinogenic risk of 10^{-4} and a hazard index of 1.

An evaluation of remedial alternatives was conducted addressing the response of the alternatives to specific criteria including: protection of human health and the environment; compliance with Applicable or Relevant and Appropriate Requirements (ARARs); long-term effectiveness and permanence; reduction of toxicity, mobility, and volume through treatment; short-term effectiveness; implementability; and cost.

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Acronyms and Abbreviations

ADA	Ammunition Demolition Activity Area
af	Acre Feet
amp	Amperes
AP	Averaging Period
APC	Air Pollution Control
ARARs	Applicable or Relevant and Appropriate Requirements
ATSDR	Agency for Toxic Substances and Disease Registry
AWQC	Ambient Water Quality Criteria
BACT	Best Available Control Technology
BAF	Bioavailability Factor
BCF	Bioconcentration Factor
BDAT	Best Demonstrated Available Treatment Technology
BRAC	Base Realignment and Closure
°C	Degrees Celsius
C	Concentration
CA	Concentration in Air
CAA	Clean Air Act
CAG	Carcinogen Assessment Group, EPA
CBG/WB	Cemented Basalt Gravel/Weathered Basalt
cfs	Cubic feet per second
CE	Combustion Efficiency
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CF	Conversion Factor
CFR	Code of Federal Regulations
cm	Centimeter
CO	Carbon Monoxide
CPF	Cancer Potency Factor
CRLs	Certified Reporting Limits
CS	Concentration in Soil
CW	Concentration in Water
CWA	Clean Water Act
DAT	Drill and Transfer
DDD	1,1-dichloro-2,2-bis (p-chlorophenyl) ethane
DDE	Dichlorophenyl-dichloro-ethylene
DEQ	Department of Environmental Quality
DDT	Dichlorodiphenyltrichloroethane
DMRO	Defense Re-utilization Marketing Office
2,4-DNT	2,4 Dinitrotoluene
2,6-DNT	2,6-Dinitrotoluene
DNB	1,3-Dinitrobenzene
DoD	Department of Defense
DOE	Department of Energy
DRE	Destruction and Removal Efficiency
EA	Ecological Assessment
EMPA	Ethyl Methyl Phosphonic Acid
EPA	U.S. Environmental Protection Agency

Acronyms and Abbreviations

EPIC	Environmental Photographic Information Center
°F	Degrees Fahrenheit
FFA	Federal Facility Agreement
FS	Feasibility Study
ft	feet
GAC	Granular Activated Carbon
gpm	Gallons per Minute
GB	Non Persistent Nerve Agent
GW	Ground Water
H	Mustard Chemical Agent
HA	Health Advisory
HBRA	Human Health Baseline Risk Assessment
HCl	Hydrochloric Acid
HEA	Health Effects Assessment
HEAST	Health Effects Assessment Summary Tables
HI	Hazard Index
HMX	High Melting Explosive (octahydro- 1,3,5,7-tetranitro-1,3,5,7-tetrazocine)
HQ	Hazard Quotient
HRS	Hazard Ranking System
ID	Induced Draft
IMPA	Isopypropyl Methyl Phosphonic Acid
in	Inch
IR	Incremental Risk
IRIS	Integrated Risk Information System
K_d	Soil/Water Partition Coefficient
K_{ow}	Octanol/Water Partition Coefficient
K_p	Permeability Constant
Kv	Vertical Hydraulic Conductivity
KVA	Kilovolt Amps
lb	Pound
LD_{50}	Lethal Dose to 50 Percent of the Study Population
LDR	Land Disposal Regulations
LTRA	Long-Term Remedial Action
M	Million
MAIV	Mechanically Agitated In-Vessel
MCL	Maximum Contaminant Level
µg/g	Micrograms per Gram (parts per million)
µg/l	Micrograms per Liter (parts per billion)
mg/kg	Milligrams per Kilogram (parts per million)
mg/L	Milligrams per Liter (parts per million)
MOC	Method of Characteristics
MSL	Mean Sea Level
NAAQS	National Ambient Air Quality Standards
NB	Nitrobenzene
NCP	National Oil and Hazardous Substances Contingency Plan

Acronyms and Abbreviations

NEPA	National Environmental Policy Act
NOAELs	No Observed Adverse Effect Levels
NPDWS	National Primary Drinking Water Standards
NPL	National Priorities List
NPV	Net Present Value
NSR	New Source Review
OAR	Oregon Administrative Rules
ODEQ	Oregon Department of Environmental Quality
O&M	Operating and Maintenance
ORNL	Oak Ridge National Laboratory
OSHA	Occupational Safety and Health Administration
OU	Operable Unit
OU-1	Operable Unit Number 1 (Inactive Landfills)
OU-2	Operable Unit Number 2 (Active Landfill)
OU-3	Operable Unit Number 3 (Ground Water Contamination from the Explosives Washout Lagoons)
OU-4	Operable Unit Number 4 (Ammunition Demolition Activity Area)
OU-5	Operable Unit Number 5 (Miscellaneous Sites)
OU-6	Operable Unit Number 6 (Explosives Washout Plant)
OU-7	Operable Unit Number 7 (Washout Lagoon Soils)
OU-8	Operable Unit Number 8 (Deactivation Furnace and Surrounding Soils)
PA	Preliminary Assessment
PCBs	Polychlorinated Biphenyls
PCC	Primary Combustion Chamber
PIC	Products of Incomplete Combustion
pg/m^3	Picograms per Cubic Meter
PHRED	Public Health Risk Evaluation Data Base
POHC	Principal Organic Hazardous Constituents
POTW	Publicly Owned Treatment Works
PPLV	Preliminary Pollutant Limit Value
PPMW	Parts per Million by Weight
PRGs	Preliminary Remediation Goals
PSD	Prevention of Significant Deterioration
psi	Pound per Square Inch
PVC	Polyvinyl Chloride
QA/QC	Quality Assurance/Quality Control
RA	Risk Assessment
RAC	Remedial Action Criteria
RAGS	Risk Assessment Guidance for Superfund
RAO	Remedial Action Objective
RCRA	Resource Conservation and Recovery Act
RDX	Royal Demolition Explosive (hexahydro-1,3,5-trinitro-1,3,5-triazine)
RfD	Reference Dose

Acronyms and Abbreviations

RFNA	Red Fuming Nitric Acid
RI	Remedial Investigation
ROD	Record of Decision
RTECS	Registry of Toxic Effects of Chemical Substances
SARA	Superfund Amendments and Reauthorization Act of 1986
SCC	Secondary Combustion Chamber
SDWA	Safe Drinking Water Act
sec	Second
SF	Slope Factor
SMCL	Secondary Maximum Contaminant Level
SPPPLV	Single Pathway Preliminary Pollutant Limit Value
TAL	Target Analyte List
TBC	To Be Considered
TCLP	Toxicity Characteristic Leaching Procedure
TDS	Total Dissolved Solids
TSD	Treatment, Storage, and Disposal Facility
Tetryl	2,4,6-Tetranitro-N-methylaniline
THC	Total Hydrocarbon Concentration
TICs	Tentatively Identified Compounds
TLV	Threshold Limit Value
TOC	Total Organic Carbon
TNB	1,3,5-Trinitrobenzene
TNT	2,4,6-Trinitrotoluene
TSS	Total Suspended Solids
TWA	Time-Weighted Average
TWA	Total Waste Analysis
UMDA	Umatilla Depot Activity
UR	Under Review
USACE	U.S. Army Corps of Engineers
USAEC	U.S. Army Environmental Center
USATHAMA	U.S. Army Toxic and Hazardous Materials Agency
UV	Ultraviolet
UXO	Unexploded Ordnance
V	Volts
VX	Persistent Nerve Agent
XRF	X-Ray Fluorescence
yd^3	Cubic Yards
yr	Year

1.0 Introduction

This report presents the results of the Feasibility Study (FS) performed for the remediation of the ground water associated with the Explosive Washout Lagoons (Site 4) at the Umatilla Depot Activity (UMDA) near Hermiston, Oregon. This report was prepared by Arthur D. Little, Inc., for the U.S. Army Environmental Center (AEC) under Task Order No. 2 for Contract No. DAAA15-91-D-0016. The FS has been conducted in accordance with the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) of 1980, as amended by the Superfund Amendments and Reauthorization Act (SARA) of 1986 and its governing regulations, the National Contingency Plan (NCP) 40 CFR Part 300.

Eight operable units (OUs) have been identified at the UMDA site based on the results of the Preliminary Assessment (Dames & Moore, 1990) and the Remedial Investigation (RI) (Dames & Moore, 1992a):

- Inactive Landfills
- Active Landfill
- Ground Water Contamination from the Explosive Washout Lagoons
- Ammunition Demolition Area (ADA)
- Miscellaneous Sites
- Explosive Washout Plant (Building 489)
- Washout Lagoon Soils
- Deactivation Furnace and Surrounding Soils

This FS is focused on the evaluation of remedial alternatives for ground water contamination from the Explosive Washout Lagoons (Site 4), which has been designated as Operable Unit 3 (OU-3). The other seven UMDA OUs are being evaluated in separate feasibility studies and other documents.

1.1 Purpose and Organization of Report

1.1.1 Purpose

UMDA is a U.S. Army ordnance depot located near Hermiston, Oregon. From the mid-1950s to 1965, explosives, contaminated sludges, and liquid wastes generated at the UMDA Washout Plant were discharged and allowed to collect and infiltrate into the soil at the Explosive Washout Lagoons. Explosives contamination of the soils and ground water led to its inclusion on the National Priorities List by EPA.

This FS addresses the ground water contamination resulting from the discharge activities to the Explosive Washout Lagoons from the Explosive Washout Plant (Building 489). The risks associated with potential future exposure to the contaminated ground water associated with the Explosive Washout Lagoons exceed the National Contingency Plan

(NCP) guidelines for carcinogenic and non-carcinogenic risks and indicate that remediation is required. These risks are based on the potential future release of the UMDA site to the general public for residential or light industrial development as part of the Army's Base Realignment and Closure Program.

This FS follows the guidelines provided in the EPA's *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA* (EPA, 1988) including defining the contaminants of concern when compared to naturally occurring background levels (such as metals), and developing, screening, and evaluating ground water remedial action alternatives. The results of this evaluation will be used by the Army, in consultation with the Environmental Protection Agency (EPA) and the Oregon Department of Environmental Quality (ODEQ), to propose a preferred remedial action plan for the remediation of the ground water at Site 4. After the Proposed Plan is reviewed by the public, the Army and EPA will formalize the ground water remedial action decision in a Record of Decision (ROD) document with concurrence from ODEQ. A similar process will be followed for the seven other OUs.

The NCP encourages the evaluation of innovative technologies where they might offer the "potential for comparable or superior treatment performance or implementability, fewer or lesser adverse impacts... or lower costs for similar... performance than demonstrated technologies" [40 CFR 300.430 (a)(1)(iii)(E)]. As a baseline for these technologies, the impact of taking no action at the site is also presented. Other potentially applicable remedial technologies are discussed briefly in the technology screening section.

The FS is also intended to satisfy the requirements of section 102(2)(C) of the National Environmental Policy Act of 1969 (NEPA). The FS evaluated both the short-term and long-term impacts of several alternatives, including no action. In addition, the NEPA public review requirements will be met during the public review of the Proposed Plan as required by CERCLA prior to issuance of the ROD.

1.1.2 Organization

As the first step in the FS process, existing data and information on UMDA and Site 4 were compiled, summarized, and interpreted. This data and information are presented in Section 1.2, Background Information (summarized from the RI Report). This background information serves to establish a historical perspective of the site and provide an understanding of the nature and extent of the contamination. In addition, the RI data were the basis for the Human Health Baseline Risk Assessment (Dames & Moore,1992b), the results of which are summarized in Section 2.0, Identification and Screening of Technologies.

Based on the interpretations and analyses of the site data, remedial action objectives were defined, and possible general response actions and associated remedial technologies were identified. The response actions and the remedial technologies were screened, first for general feasibility, and then in more detail on the basis of effectiveness, implementability, and cost. Those technologies that survived the screening were assembled into remedial alternatives. The remedial goals and objectives and the results of the screening analysis are presented in Section 2.0, Identification and Screening of Technologies.

Based on the results of the identification and screening of technologies, the candidate remedial technologies and process options were organized into remedial alternatives that could be evaluated in the detailed analysis. The Remedial Investigation/Feasibility Study (RI/FS) guidance allows, at this point in the FS, for a screening of the remedial alternatives if the number of alternatives is too great for them all to be evaluated in the detailed analysis. This step is not performed in every FS and was found not to be necessary for the evaluation of the remedial alternatives for the ground water at the Explosive Washout Lagoons. The remedial alternatives are developed and presented in Section 3.0, Development and Screening of Alternatives.

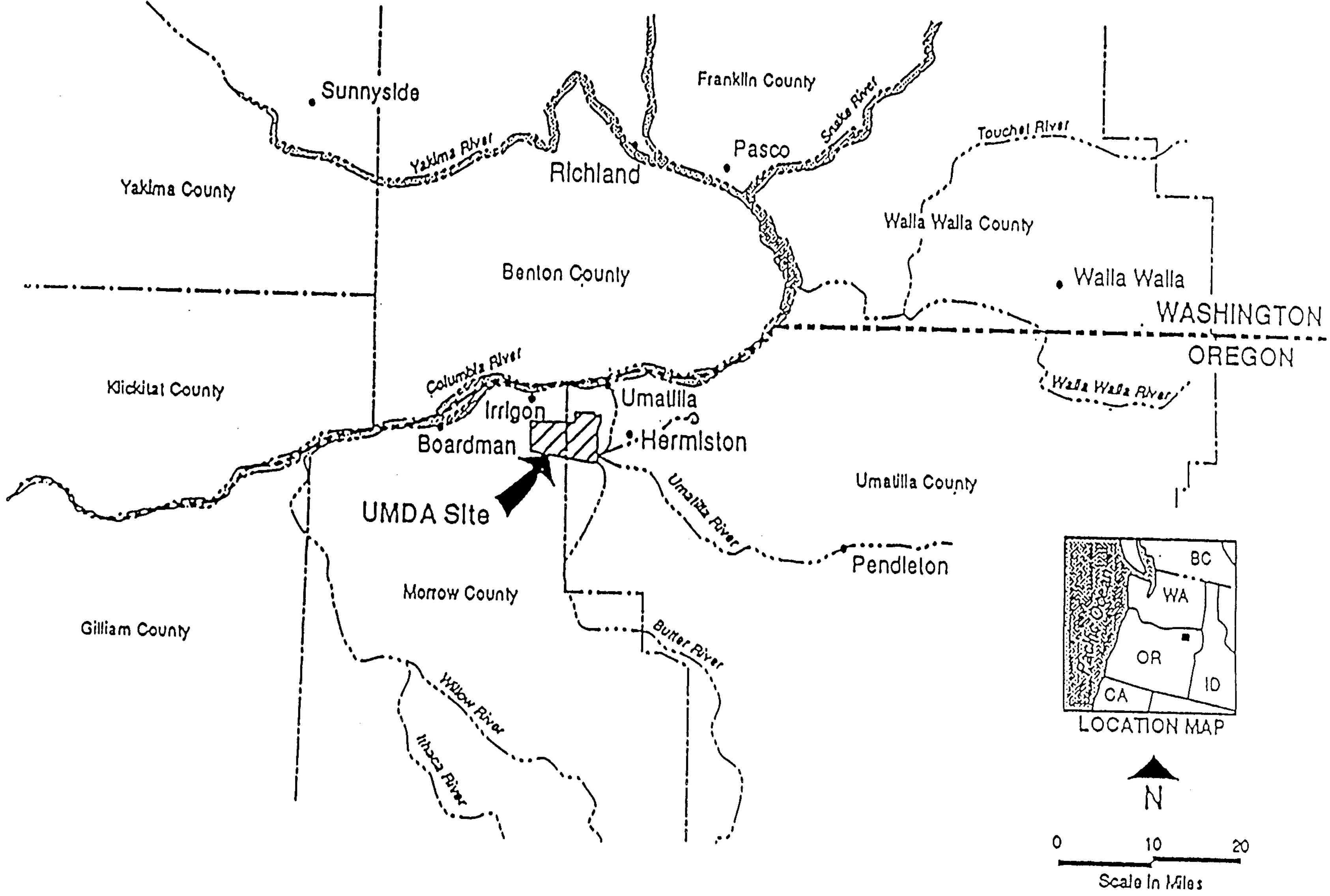
The alternatives assembled, following the screening, were evaluated in greater detail. A process for implementing each alternative was developed, and the alternatives were considered in terms of how well each would meet the nine evaluation criteria specified in the NCP. After the individual evaluations, the alternatives were compared against each other to identify strengths and weaknesses. These evaluations are presented in Section 4.0, Detailed Analysis of Alternatives.

1.2 Background Information

This section describes the background and physical setting of UMDA and Site 4, including the nature and extent of the existing contamination at the site. The primary references for this are the installation-wide Preliminary Assessment (Dames & Moore, 1990), the Remedial Investigation (Dames & Moore, 1992a), and the Intermediate and Alluvial Well Installation Report (Dames & Moore, 1993). Also included in this section is a summary of the Human Health Baseline Risk Assessment (HBRA) (Dames & Moore, 1992b).

1.2.1 Site Description

1.2.1.1 General. UMDA is located in northeastern Oregon on the border of Umatilla and Morrow counties near the city of Hermiston, as shown in Figure 1-1. It was established by the Army in 1941 as an ordnance facility for storing conventional munitions. Subsequently, the function of the facility was extended to include ammunition demolition (1945), renovation (1947), and maintenance (1955). In 1962, the Army began to store chemical-filled munitions and containerized chemical agents at


Sunnyside
Yakima River
Yakima County
Richland
Franklin County
Pasco
Snake River
Touchet River
Walla Walla County
Walla Walla
WASHINGTON
OREGON
Walla Walla River
Benton County
Klickitat County
Columbia River
Irrigon
Umatilla
Boardman
Hermiston
UMDA Site
Umatilla River
Umatilla County
Pendleton
Morrow County
Gilliam County
Butter River
Willow River
Ithaca River
BC
WA
OR
ID
CA
LOCATION MAP
N
0
10
20
Scale In Miles

PREPARED FOR: UMATILLA Washout Plant FS			SOURCE: Umatilla Depot Activity Washout Lagoons Soil Record of Decision (Sept. 1992)
DATE: Feb.. 1993	SCALE: AS SHOWN	DWG. NO. 67062-010	

TITLE: FIGURE 1-1: FACILITY LOCATION MAP
UMATILLA DEPOT ACTIVIT

the facility. UMDA continues to operate today as a munitions storage facility, and is scheduled to be involved in the Army's Chemical Demilitarization Program.

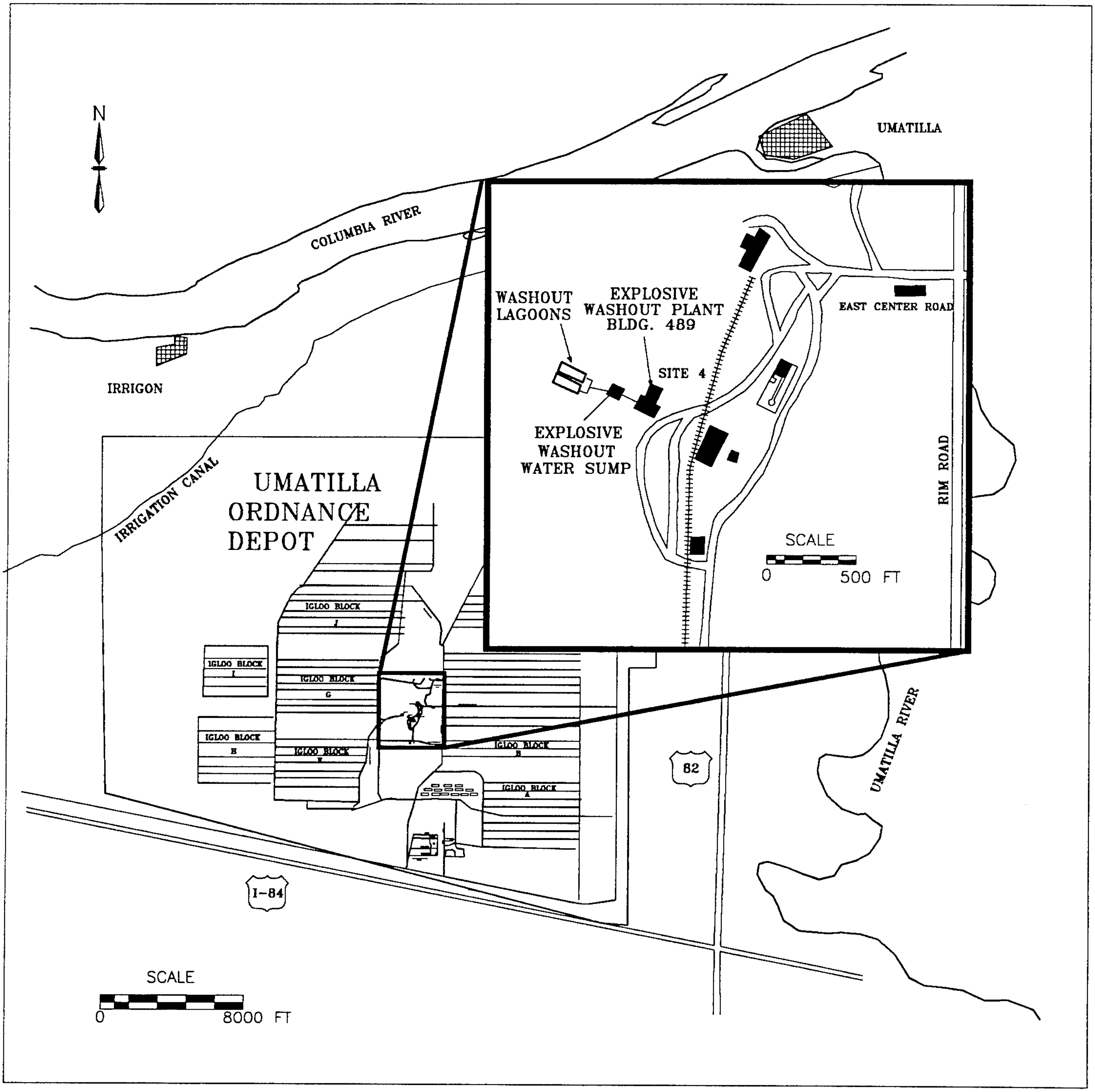
The facility occupies a roughly rectangular area of 19,728 acres; 17,054 acres are owned by the U.S. Government, while the remainder are controlled by restrictive easements that provide a safety zone around the facility. Although ownership of the latter is private, the easements grant perpetual rights to the U.S. Government, including the right to prohibit human habitation and to remove buildings. The owners retain the right to farm the lands and to graze livestock. The UMDA facility is currently one of several installations scheduled for realignment under the Department of Defense (DoD) Base Realignment and Closure (BRAC) program. Under this program, the Army is required to realign the conventional ammunition storage mission to another Army installation. UMDA cannot be closed at this time due to the scheduled demilitarization of the chemical agent stockpile stored there. However, following the completion of that mission, the possibility exists that UMDA may be evaluated again for closure and the Army could eventually vacate the site and relinquish ownership to another governmental agency or private interests. Although potential future use of the site beyond that time has not been determined, either light industrial or residential use is a possibility. Industrial use is considered to be the most likely future use scenario. Because of UMDA's uncertain future, the RI and this FS have considered future non-Army uses.

The Explosive Washout Lagoons (Site 4) are located in the east-central portion of UMDA near the Explosive Washout Plant (Site 5), as seen in Figure 1-2. The site consists of two adjacent, unlined lagoons, each approximately 25 by 70 feet and six feet deep. The lagoons were used for infiltration of wastewater from the Explosive Washout Plant during the 1950s and 1960s.

The wastewater was discharged from the building to the lagoons via a metal trough. The lagoons were used alternately, to allow the wastewater time to infiltrate. Sludge residue at the lagoon bottoms was collected, allowed to dry, and burned at the Ammunition Demolition Activity (ADA) area. The wastewater, also known as "pink water," contained high concentrations of explosives. An estimated 85 million gallons of wastewater were discharged into the lagoons during their operation. The types of disposal activities involved a range of explosive and related compounds including:

- 2,4,6-trinitrotoluene [TNT]
- 1,3-dinitrobenzene [DNB]
- 1,3,5-trinitrobenzene [TNB]
- 2,4- and 2,6-dinitrotoluene [DNT]
- nitrobenzene [NB]
- hexahydro-1,3,5-trinitro-1,3,5-triazine [RDX]
- octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine [HMX]
- n, 2,4,6-tetranitro-N-methylaniline [tetryl]

Figure 1-2: Location of Explosive Washout Lagoons at Site 4


N
UMATILLA
COLUMBIA RIVER
IRRIGON
IRRIGATION CANAL
UMATILLA ORDNANCE DEPOT
IGLOO BLOCK J
IGLOO BLOCK I
IGLOO BLOCK G
IGLOO BLOCK H
IGLOO BLOCK F
IGLOO BLOCK E
IGLOO BLOCK A
I-84
82
UMATILLA RIVER
SCALE
0
8000 FT
WASHOUT LAGOONS
EXPLOSIVE WASHOUT PLANT BLDG. 489
SITE 4
EXPLOSIVE WASHOUT WATER SUMP
EAST CENTER ROAD
RIM ROAD
SCALE
0
500 FT

1.2.1.2 Regional and Installation Setting

1.2.1.2.1 Topography and Surficial Geology. The portion of Oregon within an approximate 50-mile radius of UMDA includes parts of two geomorphic regions (Walker, 1977), the Deschutes-Umatilla Plateau and the Blue Mountains (Figure 1-3). Both of these regions lie at least partly within the Umatilla River Basin.

The Deschutes-Umatilla Plateau has relatively little relief. It gradually rises southward from elevations near 260 feet mean sea level (MSL) at the Columbia River to approximately 800 feet at the foot of the Blue Mountains. Near-surface deposits underlying the Plateau consist primarily of Miocene basalt flows, basalt debris and silts deposited as alluvial fans, Quaternary silts and clays, and Quaternary alluvial gravel and sand deposited by catastrophic flooding of the Columbia River (Walker, 1977).

The edge of the Blue Mountains lies approximately 40 miles south and southeast of UMDA. The Blue Mountains reach elevations ranging from 3,500 to 6,000 feet. The mountains are considerably dissected by streams, which have eroded many of the steep-walled canyons (Hogenson, 1964). Near-surface deposits are primarily basalt and rhyolitic tuffs, with smaller areas of metamorphosed sedimentary and volcanic rocks of probable Triassic age, and diorite and other intrusive rocks of provable Cretaceous age. The topography of the UMDA site, illustrated in Figure 1-4, can be naturally divided into three areas: Coyote Coulee, sloping lands east of the coulee, and rolling hills west of the coulee.

Coyote Coulee is a linear depression, about 0.25 mile wide, that trends north-northeast to south-southwest across UMDA. About one-third of UMDA lies east of Coyote Coulee. The east side of the coulee is a steep escarpment about 50 feet high. Although the land rises westward from the bottom of the coulee, the top of the escarpment is at a higher elevation than any nearby land west of the escarpment along most of the length of the coulee. The coulee is thus asymmetrical, unlike an erosional canyon, where the elevation of the top of both canyon walls is generally the same. The top of the escarpment is near 650 feet in the north half of UMDA, but slopes southward to 600 feet near the southern boundary. The escarpment vanishes quite abruptly at the southern boundary. East of Coyote Coulee, the surface slopes smoothly to the southeast, away from the escarpment, at a slope of approximately 50 feet per mile (ft/mi). The principal exceptions are a low hill near the southeast corner of UMDA, and a nearly level area around the administration area. West of Coyote Coulee, the surface consists largely of rolling hills. The highest hill (677-foot elevation) is near the northern boundary, just west of Coyote Coulee. A broad area of high ground extends to the southwest from this hill; from the high ground, the surface slopes with many irregularities to the northwest and south. The northern half of the area west of Coyote Coulee has many linear hills and valleys, trending east-northeast to west-southwest, 10 to 20 feet high and up to 0.5 mile in length. These

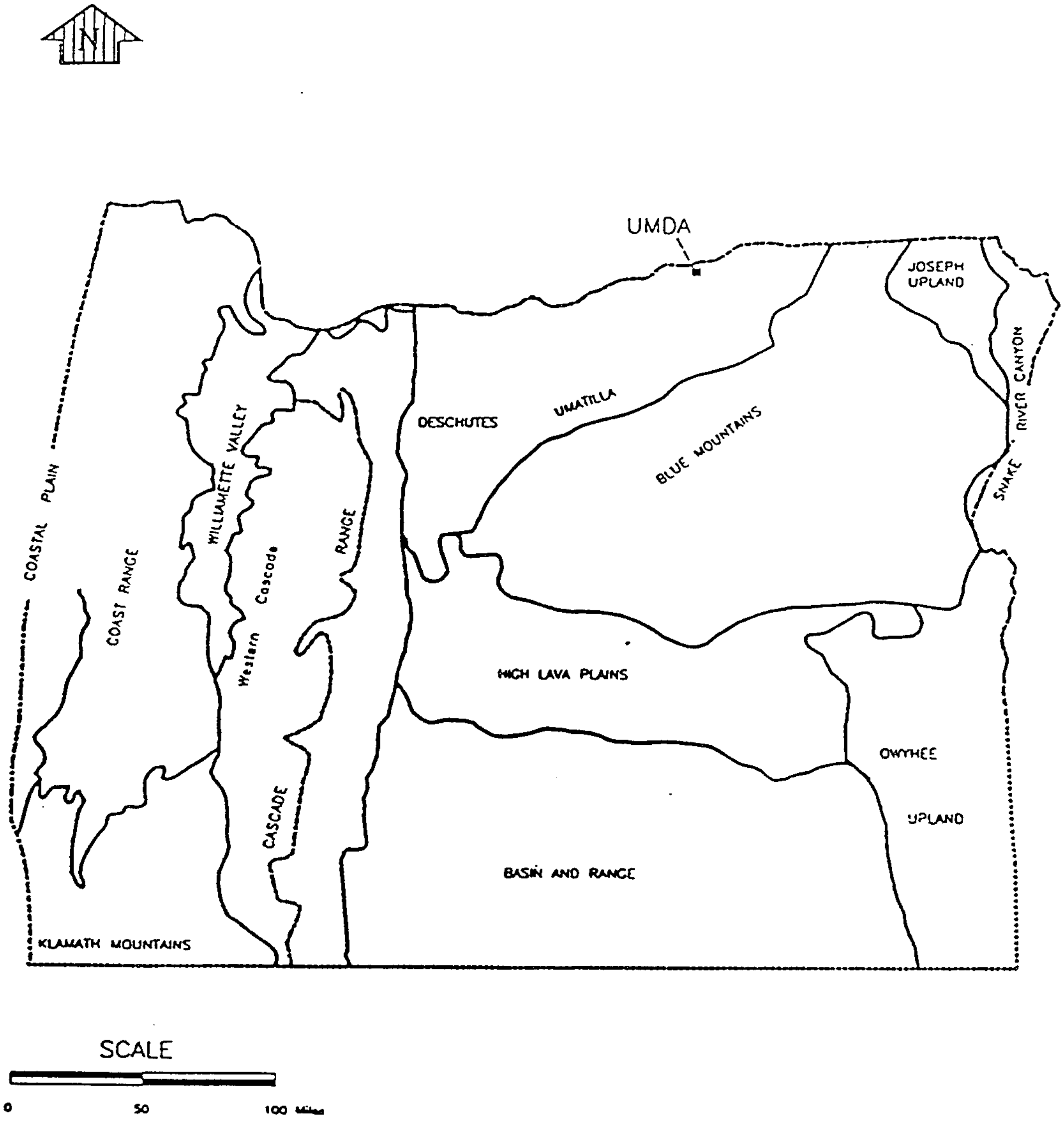
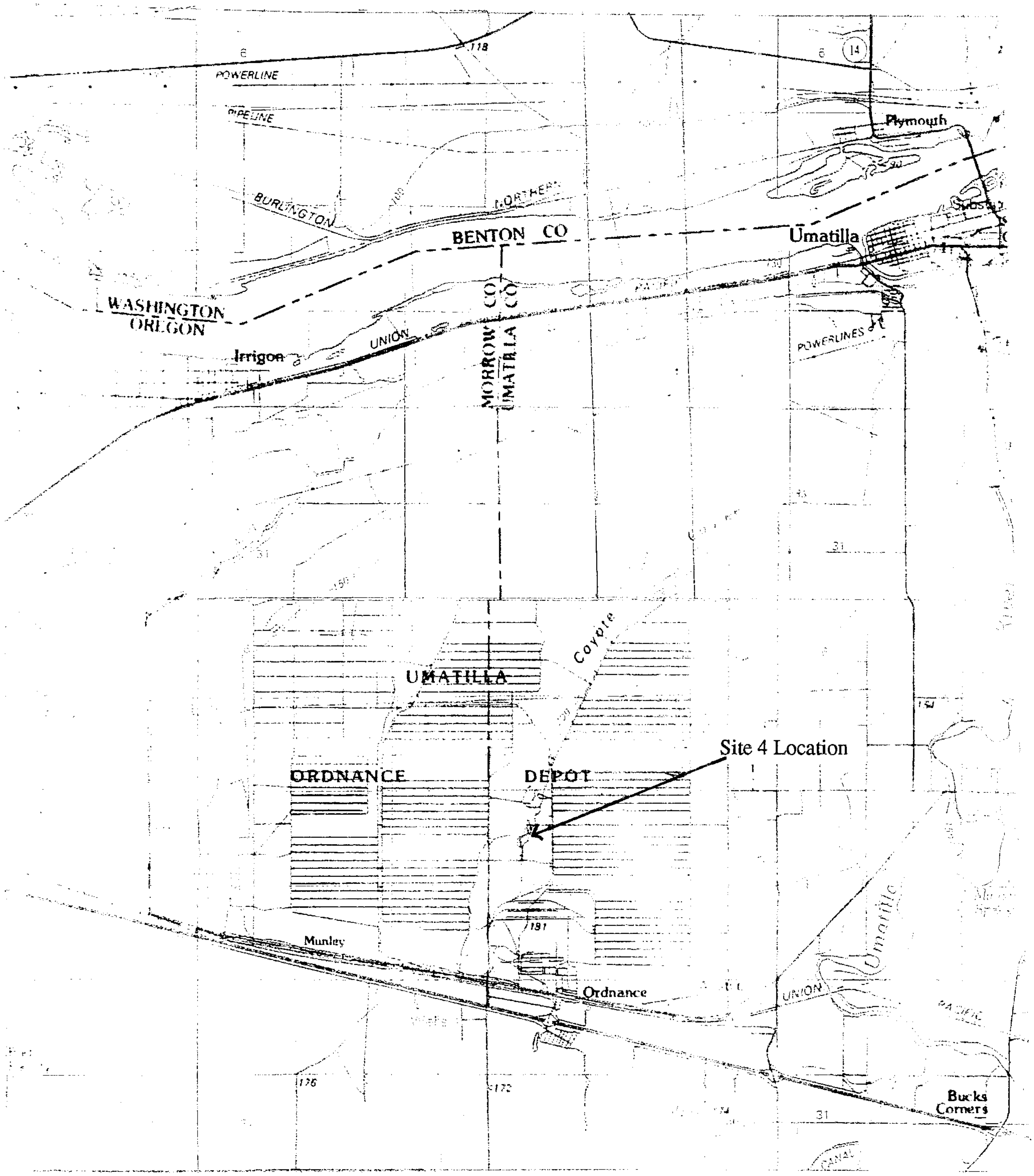

N
UMDA
JOSEPH UPLAND
DESCHUTES
UMATILLA
BLUE MOUNTAINS
SNAKE RIVER CANYON
COASTAL PLAIN
COAST RANGE
WILLIAMETTE VALLEY
Western Cascade
CASCADE RANGE
HIGH LAVA PLAINS
OWYHEE UPLAND
BASIN AND RANGE
KLAMATH MOUNTAINS
SCALE
0
50
100 Miles

Figure 1-3: Geomorphic Regions of the Area near UMDA. UMDA lies within the Deschutes - Umatilla Plateau.

TITLE FIGURE 1-3: GEOMORPHIC REGIONS OF THE AREA NEAR UMDA		
PREPARED FOR: UMATILLA	SOURCE: AFTER WALKER, 1977, AS MODIFIED FROM DICKEN, 1950	
DATE: OCT. 1992	SCALE AS SHOWN	DWG. NO 67062-014


118
14
POWERLINE
PIPELINE
Plymouth
BURLINGTON
NORTHERN
BENTON CO
Umatilla
WASHINGTON
OREGON
UNION
PACIFIC
Irrigon
MORROW CO
UMATILLA CO
POWERLINES
31
Coyote
UMATILLA
ORDNANCE
DEPOT
Site 4 Location
181
Munley
Ordnance
UNION
PACIFIC
Umatilla
176
31
Bucks Corners
CANAL
N

Note: Horizontal Lines within UMDA area are igloo storage areas.

PREPARED FOR: UMATILLA Washout Plant FS			**Figure 1-4: Topography of UMDA** Source: USGS
DATE: March 1993	SCALE: 1:100,000	DWG. NO.: 67062-022	

features may be large ripples associated with catastrophic flooding that occurred during drainage of Glacial Lake Missoula.

No natural streams occur within UMDA because of highly permeable soil. Drainage patterns are very poorly developed because of highly permeable soil, low precipitation, and the recent formation of the landscape. No direct information on storm water drainage is available for most of UMDA. Storm water runoff apparently does not travel far, except near the administration area, where runoff is collected by storm sewers. Many areas of closed drainage exist, particularly west of Coyote Coulee, with the largest about 100 acres in size. Surface water runoff generally follows topography and flows in a north-northwest direction. Drainage patterns are poorly developed. As shown in Figure 1-4, the washout lagoon's ground water OU lies beneath Coyote Coulee and its vicinity.

1.2.1.2.2 Stratigraphy. This section provides an overview of the stratigraphy of UMDA, discussing only the geological units investigated by drilling during previous on-post investigations, the RI, and post RI investigations such as the (Intermediate and Alluvial Well Installation Report (Dames & Moore, 1993).

The RI discussed three distinct geologic units underlying UMDA. These are, from oldest to youngest, Miocene basalt flows and associated interbed deposits, Pleistocene alluvial deposits, and an aeolean mantle. Detailed descriptions of each unit follow. The interpretation of the geology has changed somewhat during the past investigations, particularly in relation to the top basalt layer, however, the most recent interpretation of the stratigraphy has been used in the evaluation of technologies and alternatives.

Columbia River Basalt Flows and Interbeds. A total of six individual basalt flows and associated interbeds have been penetrated by wells at UMDA. The three uppermost basalt flows and interbeds are part of the Saddle Mountain Formation and include, from youngest to oldest, the Elephant Mountain Member, the Rattlesnake Ridge Interbed, the Pamona Member, the Selah Interbed, the Umatilla Member and the Mabton Interbed. The next three oldest basalt flows, penetrated by UMDA water supply wells supply-6 and supply-7, are thin flows that comprise the Frenchman Springs Member of the Wanapum Basalt. The interbeds in the Frenchman Springs Member are unnamed.

In general, the basalt flows and interbeds are lithologically consistent (but not homogeneous), and laterally continuous across UMDA. Basalt flowtops are moderately weathered, vesicular, and highly fractured. This zone grades downward to less weathered massive basalt with fewer fractures. The base of the basalt flows is relatively sharp. Interbeds are sedimentary layers that lie between basalt flows. Basalt gravel, sands, silts and tuffaceous materials are commonly present in the interbeds. The interbeds are much thinner and generally much more permeable than the basalt layers. Because the interbeds may be partially derived from eroded basalt, they can be difficult to distinguish from the weathered basalt flowtops during drilling.

The youngest basalt unit identified at Site 4 is the Elephant Mountain Member. The identification of this unit has varied in the past but recent laboratory analyses have confirmed its correct identification:

- During the 1988 Weston investigation, three monitoring wells were installed in the upper portion of the Elephant Mountain Member. Weston concluded that the layer was the uppermost basalt unit (Weston, 1989).
- During the 1992 RI investigation, Dames and Moore concluded that the unit was too heavily weathered to be a basalt layer and that it represented either a reworked indurated basalt gravel (referred to as the "cemented basalt gravel/weathered basalt" or "CBG/WB") or a fanglomerate unit of the Alkali Canyon Formation (Dames and Moore, 1992a).
- During the post RI investigation (Dames & Moore, 1993), additional rock cores were collected and core analysis using x-ray fluorescence (XRF) was conducted. The XRF confirmed that the unit was the Elephant Mountain Member of the Saddle Mountain Formation.

The Elephant Mountain Member has a highly weathered upper surface but becomes more competent with depth. The unit is encountered at about 460 feet Mean Sea Level (MSL); this depth corresponds to between 50 and 150 feet below ground level, depending on the topography. The total unit thickness is approximately 50 to 60 feet.

Underlying the Elephant Mountain Member is a permeable zone of basalt gravel. The origin and nature of this unit has also been disputed.

- During the RI, this unit was referred to as the "underlying gravel" and was interpreted as either a clastic interbed between the Pamona Member basalt and the CBG/WB or a facies of the Alkali Canyon fanglomerate.
- During the most recent data report (Dames & Moore, 1993), Dames and Moore has reidentified this layer as the Rattlesnake Ridge Interbed. The new identification is primarily based on permeability, the structural position of the permeable layer under the Elephant Mountain Member, and the presence of 7 feet of sediments in one ground water monitoring well (4-22).

For the FS, it is unclear if this unit is the Rattlesnake Ridge Interbed. Interbeds are sedimentary deposits, of which there are little in this unit. For example, although sediments were identified in one boring, sedimentary deposits were not present in the three other monitoring borings drilled into the same layer (4-19, 4-20, 4-21). At the Hanford Site, located approximately 30 to 40 miles north of UMDA, the Rattlesnake

Ridge Interbed is known to consist of 45 to 60 feet of tuffaceous siltstone and sandstone (Hartman and Peterson, 1992). It appears that the Rattlesnake Ridge is only present on part of Site 4 and is not continuous laterally. The unit is therefore most likely the permeable flowtop of the Pamona Member with limited sedimentary, or Rattlesnake Ridge Interbed, deposits. This unit is approximately 20 feet thick at Site 4.

The second basalt flow (reported as the uppermost in the RI) is the thickest encountered, having an approximate thickness of 170 feet. This unit is interpreted to be the Pamona Member of the Saddle Mountain Basalt, based on stratigraphic characteristics and position in geologic sequence. The top of the basalt is relatively topographically flat across most of the installation. However, depths at which it is encountered in the north UMDA water supply wells (supply-6 and supply-7) are significantly deeper, indicating that the basalt dips northward in the vicinity of these wells.

The Pamona is underlain by a thinner interbed horizon that is interpreted to be the Selah Interbed. The four deep monitoring wells at Site 4 are completed in this interbed. Where fully penetrated on UMDA, the thickness of the Selah Interbed ranges from 20 to 70 feet. The top of the Pamona Member occurs beneath UMDA at elevations ranging from 300 to 404 feet above MSL, based primarily on the borehole geophysical logs.

The Selah Interbed is underlain by another basalt flow and associated interbed, which are interpreted to be the Umatilla Member and the Mabton Interbed, respectively. Only two UMDA water supply wells (i.e., supply-6 and supply-7) fully penetrate both the Umatilla Member and the Mabton Interbed; the thicknesses of the units in these two supply wells are approximately 50 and 25 feet.

These two water supply wells also penetrate at least three more thin basalt flows and associated interbeds below the Mabton Interbed. These thin basalt flows are interpreted to consist of the upper portion of the Frenchman Springs Member of the Wanapum Basalt. The Frenchman Springs Member is composed of several individual basalt flows separated by unnamed interbeds. A total thickness of over 230 feet of basalt flows belonging to the Frenchman Springs Member and associated unnamed interbeds is encountered in these two deep supply wells.

Alluvium. According to the most recent data (Dames & Moore, 1993), the alluvium can be divided into three units, from oldest to youngest, a Pleistocene lacustrine deposit, Pleistocene alluvial flood deposits, and an aeolean mantle.

During the Pleistocene, there was a cyclic failure and re-building of glacial lakes and ice dams associated with Glacial Lake Missoula, in western Montana. At the base of the alluvium, and capping the Elephant Mountain Member, is a layer of silt, clay and fine sand. This layer is interpreted to be a lacustrine deposit possibly laid down during the existence of glacial Lake Condon that formed due to constriction of the Columbia River.

This layer is approximately 20 feet thick and tends to be dry. Lake varves were identified in one well (4-22) supporting its identification as a lacustrine deposit.

During the ice-dam failures, catastrophic floods occurred that resulted in high energy deposits being laid down. The upper section of the alluvium at Site 4 is interpreted to be the result of the catastrophic floods. This deposit is characterized by fine to coarse grained sand, gravel, and cobbles. The cobbles are primarily of basalt with some quartz, feldspar and mica; both texture and lithology are variable vertically and horizontally. This unit is approximately 120 feet thick and extends from ground surface to approximately 480 feet MSL. The Coyote Coulee is considered to be a gravel/sand wave resulting from these floods.

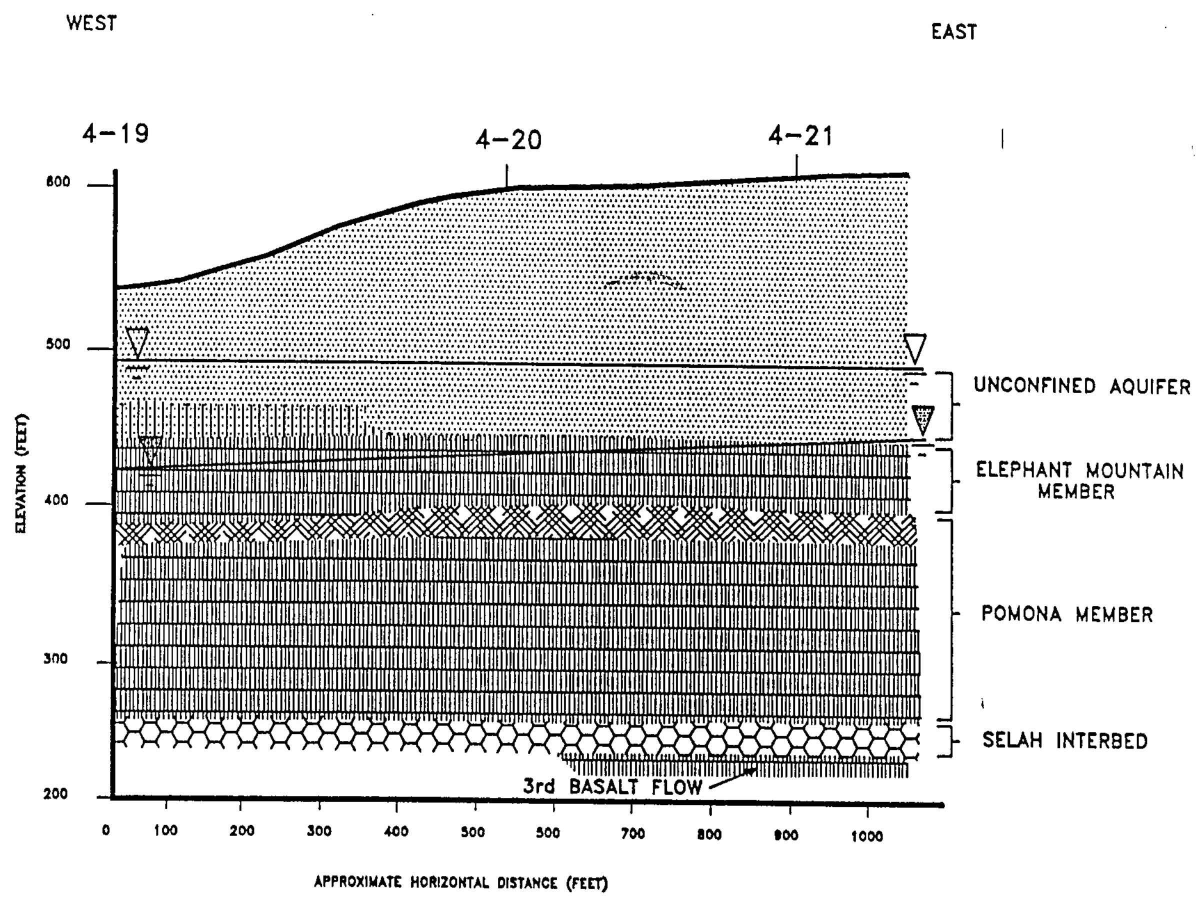
The aeolean mantle is located at ground level and consists of recent windblown deposits. The deposits consist of well sorted, angular, medium to fine sands and vary from 2 to 15 feet in thickness. The deposits are thinner east of Coyote Coulee.

The total thickness of the alluvial section penetrated in monitoring wells at UMDA ranges from approximately 42 feet in the northern part of the Ammunition Demolition Activity (ADA) area to 173 feet at Site 11 (i.e., Active Landfill) in the northeast Part of UMDA. In addition, a thickness in excess of 200 feet was estimated in one of the water supply wells based on borehole geophysical logs. Most of this variation is due to differences in surface elevation; the elevation of the base of the alluvium varies less than that of the land surface.

1.2.1.2.3 Hydrogeology. Ground water occurs beneath UMDA in a number of distinct hydrogeologic settings, in a series of relatively deep confined basalt aquifers and in a highly productive permeable unconfined aquifer in the south of UMDA (extending off-post). Figure 1-5 presents a cross-section illustrating the major hydrogeologic features of Site 4.

Confined Basalt Aquifers. Ground water occurrence in the basalt is primarily within the permeable zones that separate units of competent bedrock. The permeable zones are a combination of sedimentary interbed deposits and weathered/fractured basalt flowtops. Due to limited vertical connection between these aquifers, ground water is under confined conditions in these permeable zones. Based on borehole geophysical logs of water supply wells supply-6 and supply-7 (i.e., the deepest on-post wells), as many as six confined aquifers could be present beneath UMDA between ground surface and a depth of 700 feet.

The unweathered basalt flows act as confining beds or leaky confining beds to retard vertical movement of water between the unconfined and confined aquifers and, apparently, between different confined aquifers. Structural discontinuities may be present to provide local hydraulic connections between basalt aquifers. The vertical hydraulic


WEST
EAST
4-19
4-20
4-21
600
500
400
300
200
ELEVATION (FEET)
0
100
200
300
400
500
500
700
800
900
1000
APPROXIMATE HORIZONTAL DISTANCE (FEET)
UNCONFINED AQUIFER
ELEPHANT MOUNTAIN MEMBER
POMONA MEMBER
SELAH INTERBED
3rd BASALT FLOW

SOURCE: MODIFIED FROM INTERMEDIATE AND ALLUVIAL INSTALLATION REPORT SITE 4[8]

TITLE: STRATIGRAPHIC CROSS-SECTION BENEATH SITE 4

PREPARED FOR: UMATILLA

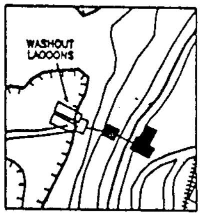
DATE: 7/93

DWG. NO. 67062-031

EXPLANATION

░	ALLUVIUM
▥	SILT AND CLAY
▩	FLOW TOP
▥	BASALT
⬡	INTERBED

LOCUS MAP


WASHOUT LAGOONS

SCALE: AS SHOWN

DRAWN BY (INITIALS) M.S.B

APPROVED BY (INITIALS)

Arthur D Little

Figure 1-5:

conductivity of the basalt has not been measured at UMDA. However, permeability data for flow interiors are available for the Hanford site in Washington (DOE, 1986). Reported horizontal permeabilities range from 1 x 10^{-7} to 1 x 10^{-10} cm/sec. Field-derived vertical permeability estimates are not available from Hanford. Based on simulations and statistical analyses of fracture data, DOE estimates that vertical permeabilities will be found to be within a factor of 10 of the horizontal conductivities.

The uppermost basalt aquifer, referred to as the "underlying gravel" in the RI (Dames & Moore, 1992a), immediately underlies the Elephant Mountain Member. This unit is comprised of the flowtop of the Pamona Member basalt with limited sedimentary deposits, possibly of the Rattlesnake Ridge Interbed. The hydraulic conductivity, based on slug tests conducted in the four new wells installed in this unit during the post-RI investigation, ranges from 277 to 624 feet/day. The Elephant Mountain Member, which acts as a confining layer to the first basalt aquifer, has a much lower hydraulic conductivity (0.01 to 0.16 feet/day), based on packer tests conducted during the same investigation. Three rounds of water level data have been collected from this aquifer (Table 1-1). The direction of ground water flow is approximately west-northwest (Ballad, 1993). There was a 23-foot drop in hydraulic head in approximately, 1,000 feet (gradient 0.02). A 30- to 45-foot decrease exists in hydraulic heads between the wells screened in this aquifer and those in the unconfined aquifer, indicating that a lack of hydraulic connection between the aquifers and that the Elephant Mountain Member acts as an effective confining layer.

Table 1-1: Water Level Elevation Data for the Intermediate Wells

Well Number	Water Level Elevation (in feet)		
	Dec. 1992[1]	Jan. 1993[2]	Oct. 1993[3]
4-19	445.23	447.76	447.31
4-20	470.90	470.50	465.41
4-21	460.68	463.20	463.06
4-22	456.45	459.34	457.73

References:

(1) Data from December 16, 1992, Intermediate and Alluvial Well Installation Report (Dames & Moore, 1993)

(2) Data from December 5-8, 1993, Personal communication between D. Vesper of ADL and W. Ballard of Dames & Moore (Ballard, 1993)

(3) Data from November 13, 1993, Personal communication between D. Vesper of ADL and T. Llewellyn of Dames & Moore (Llewellyn, 1993)

The Selah Interbed aquifer is the second basalt aquifer encountered with depth. During the RI, the depth-to-water in the Selah ranged from 55 to 155 feet below ground level

(440-470 feet MSL). Adjacent unconfined aquifer wells had water levels 35 to 55 feet higher than the Selah wells, indicating that the Selah is not well connected to the unconfined aquifer and that a strong downward vertical gradient exists between the aquifers. Ground water in this aquifer consistently flows to the northwest with some seasonal variation in water levels. The seasonal changes correspond to the irrigation season and are assumed to be the result of off-site pumpage. During the RI, the average water level elevation change, between upgradient and downgradient wells at Site 4, is 18 feet, which corresponds to an average hydraulic gradient of 0.02 feet/feet. Four pump tests were conducted in the Selah, from which transmissivity values ranging from 39 to 657 feet/day were calculated. The transmissivity, and the range of responses from the non-pumping wells, indicate that the Selah is anisotropic.

The Selah is fairly productive, yielding 29.5 gpm for a period of 8 hours at Site 4 (Dames and Moore, 1992a) and could likely have produced more if the pump had been set deeper within Well 4-10. Large yields are obtainable from water supply wells that penetrate one or more confined aquifers. Water supply well supply-1, for example, is capable of producing 1,000 gpm with 10 feet of drawdown (USACE, 1987). Therefore, this well has a relatively high specific capacity of 100 gpm/ft. Supply-5 and supply-7 have even higher specific capacities, 133 and 130 gpm/ft, respectively, but are limited to smaller yields of 500 and 650 gpm by the capacities of their pumps. The Selah is the deepest aquifer penetrated during the remedial investigations at Site 4.

Unconfined Aquifer. As previously stated, the unconfined aquifer at UMDA consists of the alluvium deposits and the weathered surface of the Elephant Mountain Member basalt. Aerially, unconfined ground water occurs in two distinct hydrogeologic units beneath UMDA, a permeable southern aquifer (termed the Ordnance Aquifer) and a less permeable northern aquifer. The behavior of ground water in these two aquifers is distinctly different.

The Ordnance Aquifer is located in the southern portion of UMDA and extends off-post both to the south and to the east, corresponding to the "Ordnance Critical Ground Water Area." To the south of UMDA, the aquifer is tapped by numerous shallow wells that produce as much as 1,000 gallons per minute. Although regional water levels have declined since initiation of irrigation pumping in the 1950s and 1960s, the specific capacities of these irrigation wells are high. The use of the aquifer has been the subject of regional studies to evaluate the impact of withdrawals and artificial recharge activities (Miller, 1985). Ground water levels in the Ordnance Aquifer have shown a net annual increase since the initiation of artificial recharge activities and reduced pumping in the 1970s.

Permeabilities of shallow wells in the southern part of UMDA (Ordnance Aquifer) are typically much greater than in wells to the north. Average permeability values from wells in the Ordnance Aquifer at Sites 4 and 12 are on the order of 2.1 x 10^{-1} cm/sec (585 ft/day), with a maximum of 9.6 x 10^{-1} cm/sec (2,721 ft/day). Ground water gradients within the Ordnance Aquifer are very low (approximately 0.00015 ft/ft), further suggesting high aquifer permeabilities. An evaluation of hydrographs from the Ordnance Aquifer monitoring wells at Sites 4 and 12 show a significant seasonal response to off-post pumping and artificial recharge activities to the south and east of UMDA.

The saturated thickness of the Ordnance Aquifer is known only at Site 4, where four monitoring wells penetrate through to the Elephant Mountain Member. At this site, the saturated thickness of the entire unconfined aquifer ranges from approximately 15 to 35 feet. This estimate includes only the saturated thickness of the alluvium exclusive of the Elephant Mountain Member. However, water levels in wells installed in the weathered and fractured surface of the Elephant Mountain Member have similar elevations to wells screened in the alluvium, indicating that the flowtop is in direct hydraulic connection with, and is therefore part of, the unconfined aquifer. The exact thickness of the flowtop that is in connection with the unconfined aquifer is unknown and likely varies across the site dependent upon the thickness of the lacustrine deposits and the degree of weathering.

Ground water flow directions in the Ordnance Aquifer at Site 4 reverse seasonally in response to off-post pumping and recharge activities. During the summer and early fall, flow is toward the east and south as irrigation activities peak. During the winter and early spring, when irrigation activities are at a minimum, ground water flow is to the north and west. It is probable that, prior to initiation of irrigation in the 1950s and 1960s, the natural direction of flow in the Ordnance Aquifer was to the northwest toward the Columbia River and, in the direct vicinity of the Umatilla River, possibly to the northeast. Currently, because water level declines have occurred in the aquifer, discharge is probably exclusively to irrigation wells. There is likely insufficient head now to drive ground water either into the finer sediments of the northern aquifer or over the top of the finer sediments within the more permeable sediments (which are now dewatered and overlie the finer northern aquifer sediments).

The Ordnance Aquifer pinches out along an east-west transect slightly north of Site 4. Ground water gradients to the south of this contact are low and reverse seasonally in response to off-post stresses. Ground water gradients to the north of this contact are much greater (0.0085 ft/ft) and show no seasonal reversals. Flow is consistently to the northwest, where it probably discharges to the Columbia River. Hydrographs of selected wells indicate that the wells do not respond to off-post irrigation activities, suggesting that they are not in hydraulic contact with the Ordnance Aquifer. Northern aquifer permeabilities are typically much less than those to the south, with an average value of 0.0095 cm/sec (27 ft/day) and a maximum value of 0.18 cm/sec (503 ft/day).

The saturated thickness of the northern aquifer beneath UMDA, exclusive of the Elephant Mountain Member is about 30 to 60 feet in most places. In the ADA area, the alluvium reaches a maximum saturated thickness of 70 feet; but, it is zero in the north, where the elevation of the top of the Elephant Mountain Member is above the water table.

1.2.1.2.4 Streams within the Umatilla Basin. UMDA is located in the Umatilla Basin. The basin's area is about 2,545 square miles (Oregon Water Resources Department, 1988). The principal stream is the Umatilla River, whose principal tributaries rise in the Blue Mountains and flow generally northward toward the Columbia River, which bounds the basin to the north. The Columbia is a major river in the area, with a mean discharge of 200,000 cubic feet per second (cfs). Its level is stabilized at an approximate elevation of 265 feet MSL by the John Day Dam. (Geraghty et al., 1973).

Mean discharge of the Umatilla River (located approximately 1 to 2 miles east of the installation boundary, depending on location) at Yoakum, 17 miles downstream from Pendleton, Oregon, was 669 cfs from 1935 to 1985 (Oregon Water Resources Department, 1988). A lower gauge at Umatilla, Oregon, near the mouth of the river, has a considerably smaller mean discharge, 490 cfs, because of irrigation diversion, and does not reflect natural streamflow. Butter Creek, the largest tributary of the Umatilla River, has a mean discharge of 28 cfs at Pine City, 20 miles above its junction with the Umatilla River.

Streamflow varies considerably through the year. At Yoakum, mean flow is 1,665 cfs during April, but decreases steadily to 91 cfs in October. During the irrigation season, most streamflow in the Umatilla River and Butter Creek is diverted for irrigation use.

Much of the northern part of the basin near the Columbia River has no (or poorly developed) surface drainage because of highly permeable soil. Surface runoff has occasionally been observed from Sand Hollow. This runoff fills depressions about 2 miles south of UMDA, from which the water infiltrates into the gravels (Miller, 1985).

1.2.1.2.5 Ground Water Use, Artificial Recharge and Water Balance. An estimated ground water balance (an accounting of gains to and losses from the ground water system) has not been reported for the entire Umatilla Basin. However, Miller (1985) provides information that makes possible an estimate of the ground water balance of the Ordnance Critical Ground Water Area (referred to below as the Ordnance Area), a 35-square-mile area that adjoins UMDA on the east and south. The Ordnance Area contains an unusually productive unconfined aquifer that has been tapped for irrigation. Additional information that supports an estimated natural recharge rate of approximately 0.5 inch per year (in/yr) is supplied by Bauer and Vaccaro (1990). The water balance primarily reflects the alluvium, though some pumping occurs from basalt aquifers. The water balance is dominated by artificial effects, as discussed below.

The water balance for the Ordnance Area is summarized in the following list, which reflects conditions from 1978 to 1984:

- Recharge to ground water

- Precipitation/infiltration	1,000 acre-feet per year (af/yr)
- Stream seepage	Unknown
- Canal leakage	11,000 af/yr
- Inflow from west	2,000 af/yr
- Artificial recharge (mean)	5,400 af/yr

- Discharge from ground water

- Springs/seepage to Umatilla River	2,000 af/yr
- Ground water outflow	Unknown
- Direct evapotranspiration	Small
- Pumping	8,600 af/yr

Ground water recharge from precipitation in the vicinity of UMDA is estimated by Bauer and Vaccaro (1990) to be approximately 0.5 in/yr or less. In the area immediately to the southeast of UMDA, however, recharge rates of approximately 2 to 5 in/yr are estimated due to irrigation activities.

Seepage from the Umatilla River probably occurs when its level is high, but the rate is unknown. Leakage from canals east of UMDA is fairly accurately measured at 11,000 af/yr (Miller, 1985). Leakage from canals south of UMDA is probably much less because of less permeable soil.

An area of 29,780 acres west of the Ordnance Area is irrigated by water from the Columbia River. In the past, excess irrigation water may have recharged ground water in this area at a fast enough rate to cause northeastward flow into UMDA from off-post.

An artificial recharge canal 1 mile south of UMDA is operated by the County Line Water Improvement District. It consists of 2.5 miles of unlined canal, 15 feet wide, that is supplied with water from the High Line Canal, which obtains water from Butter Creek. Recharge from the canal began in 1977, with recharge of 469 acre-feet (af) of water. Between 1978 and 1984, annual recharge ranged from 3,149 to 6,763 af/yr, with a mean of 5,358 af/yr. Ground water levels south of UMDA have increased approximately 12 feet since 1977, and at least half of this increase is attributed to the artificial recharge canal (Miller, 1985).

Springs occur along the Umatilla River near the northeast corner of the Ordnance Area. Their discharge, though estimated, increases markedly during the irrigation season because of leakage from nearby canals. Ground water flows out of the Ordnance Area in the subsurface, but information on gradients and flow direction is too sparse to estimate its flow rate.

Evapotranspiration directly by plants whose roots reach the saturated zone is probably slight, because in most parts of the area the depth to ground water appears to be several tens of feet.

Pumping, largely for irrigation, is the major discharger of ground water. Total pumpage (18,600 af/yr) has been relatively stable since 1971.

1.2.1.2.6 Meteorology. The following meteorological information is compiled using data from Gale Research Company (1985) and U.S. Environmental Data Service (1975).

UMDA is located within the northern portion of the Columbia Basin, which enjoys a relatively mild climate. The temperature ranges from 24° to 90°F, with a mean annual temperature of 52.6°F. Normal daily average temperatures vary from 35°F in January to 70°F in July. The mild temperatures are a result of the moderating effect of the Pacific Ocean to the west.

The majority of the moisture picked up from the Pacific Ocean falls on the western slopes of the Pacific Coast Range and the Cascades as the air mass moves eastward. Precipitation in the Hermiston area is relatively low, with an annual mean of 8.87 inches. Only about 10 percent of the annual precipitation falls in summer. For the month of January, the mean total precipitation is 1.91 inches; during July, the mean total is only 0.23 inch. The area receives an average of 9.8 inches of snow annually.

Mean relative humidity varies from 80 percent in January to only 35 percent in July. The humidity tends to be approximately five percent higher in the morning throughout the year. Consistent with the low summer humidity, 80 to 90 percent of annual evaporation occurs between May and September.

1.2.2 Nature and Extent of Contamination

Contamination has been identified in both the unconfined aquifer and the second confined aquifer at the Explosive Washout Lagoons. The spacial extent of contamination in the two aquifers is significantly different; therefore, the nature and extent of contamination is discussed separately for each aquifer.

1.2.2.1 Unconfined Aquifer. The unconfined aquifer consists of the alluvium and the weathered flowtop of the Elephant Mountain Member (Section 1.2.1.2.3, Hydrogeology). The RI presented the cemented basalt gravel/weathered basalt (CBG/WB) and the underlying gravel as part of the unconfined aquifer; however, additional studies have shown that the CBG/WB is the Elephant Mountain basalt layer (Dames & Moore, 1993). A summary of the contamination in the Unconfined Aquifer during the RI and Phase II RI program (November 1990 to December 1992) is presented in Table 1-2 along with comparison criteria (selected chemical-specific ARARs, risk-based goals, background, or detection limits [see Section 2.1.3.1, Chemical-Specific ARARs and other Preliminary Remedial Goals]).

Ground water samples were collected and analyzed from 30 wells in the sandy alluvium. The sandy alluvium includes all wells with screens in the shallow sandy alluvium. The deep alluvium is primarily silty sand and is discussed below. Contamination of explosive compounds was detected in ground water from 18 of the 30 wells. The most common contaminant was RDX, with concentrations ranging from below detection (<0.556 µg/L) to 6816 µg/L (MW-28, 2/14/91). RDX was detected above its comparison criteria (2.1 µg/L) in 16 of the locations and above 1,000 µg/L in four of the locations. RDX, the most mobile of the contaminants, has the largest plume (Figure 1-6). From the lagoon source area, the RDX plume extends primarily to the southeast with some elevated concentrations to the northwest. The plume is well delineated to the northeast and southwest where steep chemical concentration gradients are present. It appears that the irrigation-induced ground water flow direction (to the southeast) has a greater effect on contaminant migration than does the natural flow direction (to the northwest).

Other explosive compounds detected above their comparison criteria include 1,3,5-TNB, 1,3-DNB, 2,4,6-TNT, 2,4-DNT and 2,6-DNT. Compounds detected below their comparison criteria include HMX, Tetryl, and nitrobenzene. The other explosive compounds are less mobile than RDX and therefore have more localized plumes. A concentration contour map for 2,4,6-TNT has been provided as an example of the less mobile contaminant plumes in Figure 1-7.

Eleven sandy alluvium wells were sampled for inorganics. Of those wells sampled, all analyses showed that metals were below comparison criteria of either Maximum Contaminant Levels (MCLs), risk-based criteria, or background concentrations. Nitrate/nitrite was also analyzed for and found to be above the MCL in several locations but below the background level. Background concentrations for nitrate/nitrite are high at UMDA due to off-site migration from the surrounding farms.

Of the four wells in the silty sand, three had detectable explosive compounds. No explosives were detected in Well 4-15 and no explosives were detected above their comparison criteria in Well 4-12. Well 4-14, located northwest of the source, had RDX slightly above its comparison criterion. Well 4-13, southeast of the source, had both RDX and 2,4-DNT at about their comparison criteria. The highest concentration of explosives in this layer, 2,400 µg/L of RDX, was detected in Well 4-13.

Three wells are installed in the weathered portion of the Elephant Mountain Member. Two (SB-1 and SB-3) contain RDX slightly above the comparison criterion. The highest RDX concentration in this geologic structure was found at SB-2 (76 µg/L), but the concentration was unconfirmed and not found in later rounds of sampling.

Table 1-2: Summary of RI and Phase II RI Contaminant Assessment

	Frequency of Detection	Average (μg/L)	Minimum (μg/L)	Maximum (μg/L)	Comparison Criteria Concentration (μg/L)	Comparison Criteria Type
Inorganics						
Antimony	3/19	4.9	3.6	6.0	8.0	Bkgd
Arsenic	16/19	14.3	12.2	17.2	50.0	MCL
Beryllium	0/19	ND	ND	ND	4.0	MCL
Chromium	8/19	12.4	7.78	16.4	100	MCL
Copper	5/19	13.2	10.9	15.4	1,300	MCLG
Lead	8/19	2.6	1.5	4.1	15.0	MCL
Nickel	0/20	ND	ND	ND	100	MCL
Nitrate/Nitrite	80/80	13,303	14.7	48,000	54,000	Bkgd
Sodium	36/36	40,229	20,650	96,000	100,000	Bkgd
Vanadium	13/18	76.4	63.8	89.1	260	Risk-Based
Zinc	3/20	35.3	21.7	48.8	5,000	Oregon MCL
Explosives						
1,3,5 - TNB	27/123	119	0.8	441	18.0	Risk-Based
1,3 - DNB	13/123	7.6	0.6	24.4	4.0	Risk-Based
2,4,6 - TNT	20/123	1,557	0.8	3,900	2.8	Risk-Based
2,4 - DNT	16/123	255	0.8	497	0.6	CRL
2,6 - DNT	1/89	5.3	5.3	5.3	1.2	CRL
HMX	22/123	383	1.9	1,448	1,820	Risk-Based
Nitrobenzene	3/123	14.4	13.1	15.8	20.0	Risk-Based
RDX	68/123	992	2.7	6,816	2.1	CRL
Tetryl	1/123	0.8	0.8	0.8	400	Risk-Based

Notes:

Average is equal to the average of all detected concentrations.

Minimum is equal to the minimum detected value.

MCL - Maximum Contaminant Level

MCLG - Maximum Contaminant Level Goal

Bkgd - Background

CRL - Certified Reporting Limit

ND - No data

Four intermediate wells were installed below the Elephant Mountain Member to determine whether the Rattlesnake Ridge Interbed had been contaminated. The results of the first round sampling showed that all contaminants of concern were below detection limits (Lechner, 1993). Based the results of this sampling round the Army has determined that the Rattlesnake Ridge Interbed is not contaminated and, therefore, does not require remediation.

1.2.2.2 Second Confined (Selah) Aquifer. Ground water data were obtained from all four wells screened in the Selah Interbed aquifer. All of the metals were detected below their comparison criterion in all four wells, as was nitrate/nitrite.

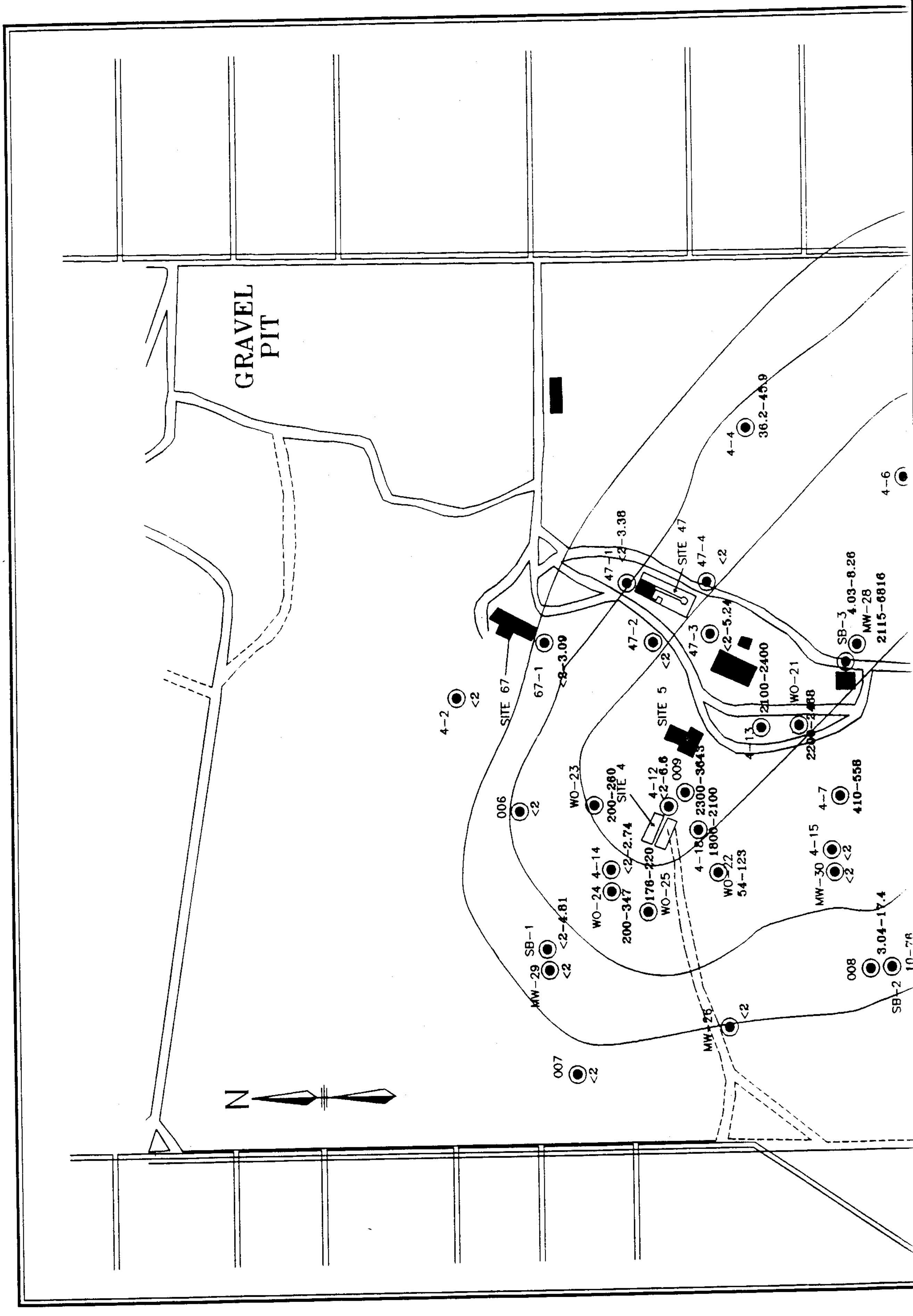
Two wells (4-10 and 4-17) are located southwest of the source area. No contaminants were detected in the southwest wells above their comparison criteria. Well 4-8 is located immediately adjacent to the source and contained both RDX and 2,4-DNT above their comparison criteria.

The highest concentration detected in the Selah aquifer was found at Well 4-9, which is located southeast of the source area. RDX was the only contaminant detected above its criteria at this location: 1,100 µg/L in October 1990 and 4,700 µg/L in February 1991. Because no contamination was found in the first confined aquifer, the Army Environmental Center has suspected that either drilling activities or possibly slight well leakage may be causing the contamination measured in the second confined aquifer. Additional time-series sampling was conducted in Wells 4-8 and 4-9 to measure the extent of contamination, and downhole video logging was conducted to investigate the integrity of the wells. The results of this work are currently being reviewed, though first indications are that second aquifer contamination did arise from a small amount of well leakage from the alluvial aquifer, and that no remedial action other than removal of the wells is needed. The Army is preparing to conduct this work in consultation with the regulatory agencies.

1.2.3 Human Health Baseline Risk Assessment

This section of the FS summarizes the risk assessment completed for Site 4 in the Final Human Health Baseline Risk Assessment (HBRA) (Dames & Moore, 1992b). Because this FS considers the ground water contamination, only those risks associated with the ground water are addressed. For a detailed presentation of the results, refer to the HBRA (Dames & Moore, 1992b).

1.2.3.1 Selection of Contaminants of Concern. The analytical results used in the HBRA are from the Enhanced Preliminary Assessment (Dames & Moore, 1990) or Remedial Investigation (Dames & Moore, 1992a). These data were selected because they represent current site conditions and because sample collection and analysis was conducted using U.S. Army Environmental Center (USAEC) protocols. The potential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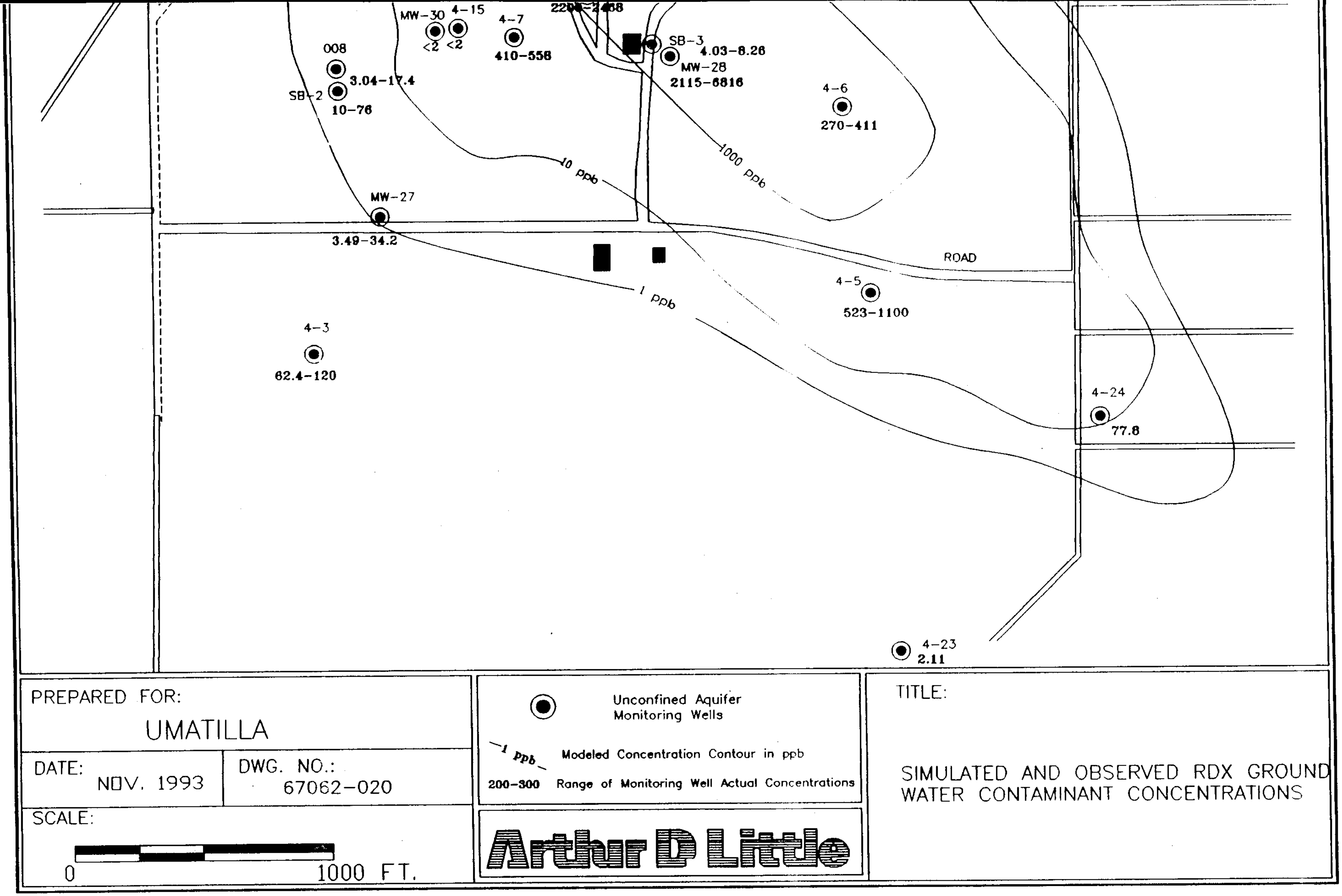
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PREPARED FOR:
UMATILLA
DATE:
NOV. 1993
DWG. NO.:
67062-020
SCALE:
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Unconfined Aquifer Monitoring Wells
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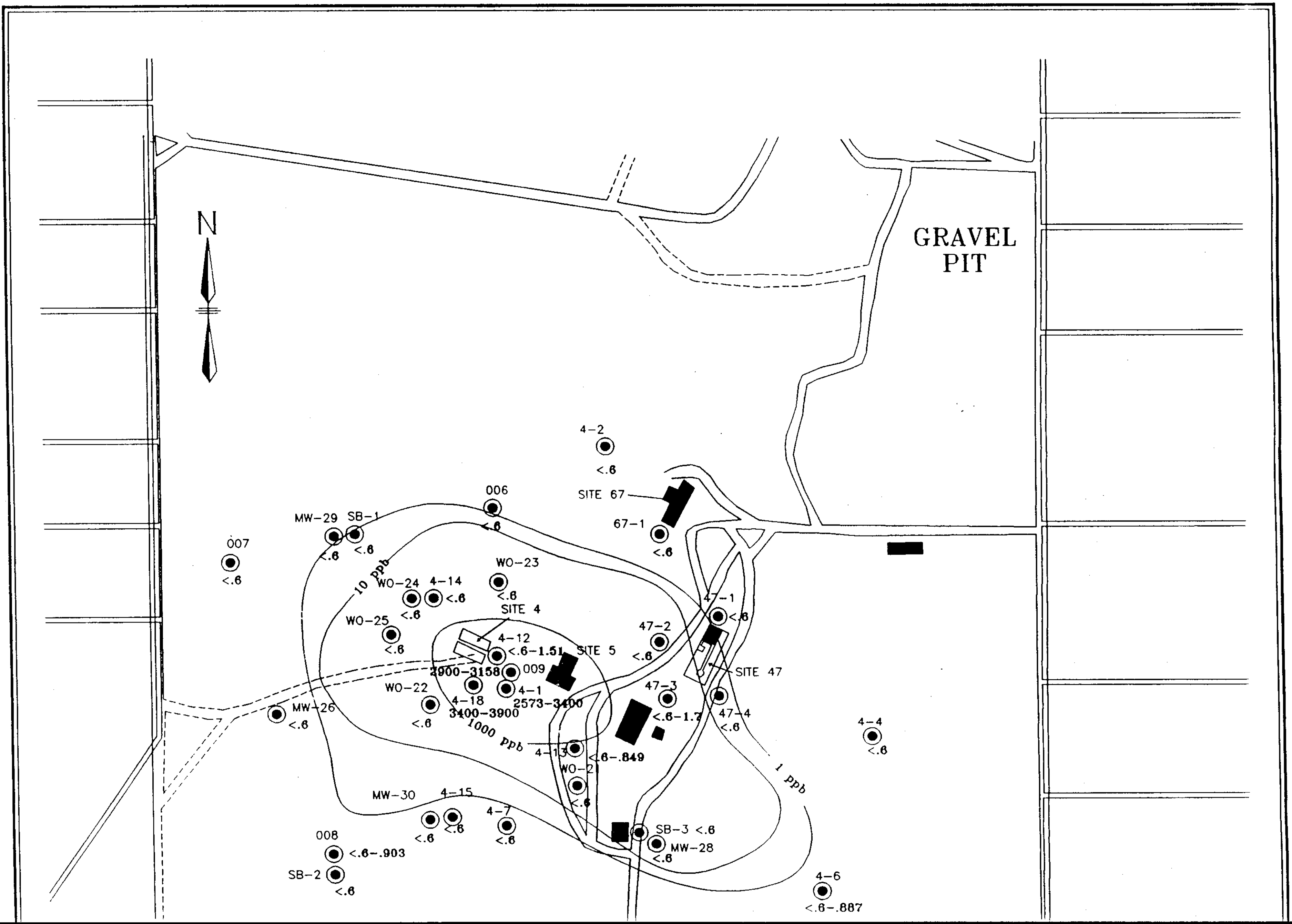
Modeled Concentration Contour in ppb
200-300
Range of Monitoring Well Actual Concentrations
Arthur D Little
TITLE:
SIMULATED AND OBSERVED RDX GROUND WATER CONTAMINANT CONCENTRATIONS

Figure 1-6: RDX Concentrations In Water Table Wells at Site 4
January/February 1991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WO-23 <.6
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WO-25 <.6
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SITE 5
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WO-22 <.6
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SITE 47
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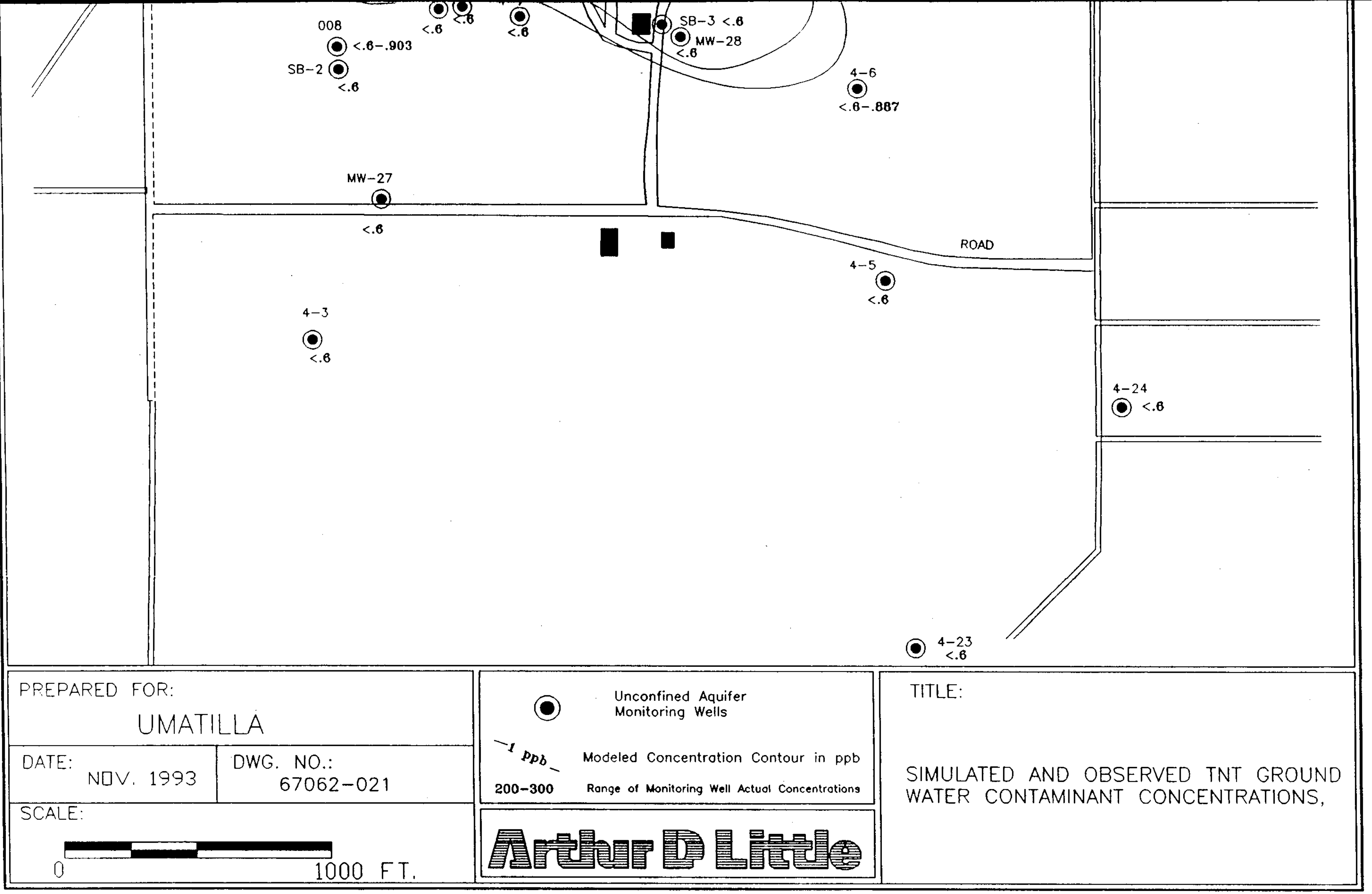
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UMATILLA
DATE:
NOV. 1993
DWG. NO.:
67062–021
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1000 FT.
Unconfined Aquifer Monitoring Wells
1 ppb
Modeled Concentration Contour in ppb
200–300
Range of Monitoring Well Actual Concentrations
Arthur D Little
TITLE:
SIMULATED AND OBSERVED TNT GROUND WATER CONTAMINANT CONCENTRATIONS,

Figure 1-7: TNT Concentrations in Water Table Wells at Site 4
January/February 1991

2 9 2

contaminants of concern from those investigations were identified using the following criteria:

- Positive detection in at least one sample in at least one medium
- Significant elevation above method blanks (5 to 10 times the method blank concentration depending on the compound)
- Inorganic compounds present at concentrations above the maximum background sample concentration
- Tentatively identified compounds (TICs) if known to be site related
- Transformation products of other contaminants of concern

The contaminants of concern identified in ground water for Site 4 are summarized in Table 1-3. The contaminants have been identified for two separate aquifers: the unconfined aquifer and the second confined aquifer. The flood gravel data include all wells installed in the unconfined aquifer. The second confined aquifer includes the four wells screened in the Selah Interbed. Ground water data from Sites 47 and 67 have been combined with Site 4 data because of the difficulty in distinguishing plumes from each source.

1.2.3.2 Toxicity Assessment. Toxicological profiles were developed for the HBRA and are included in Appendix D of that document. Information on the profiles includes, where available: non-carcinogenic effects and reference doses for oral ingestion and inhalation; carcinogenic effects, slope factors and weights-of-evidence for oral ingestion, dermal absorption, and inhalation; and references.

Reference dose (RfD) values are used to evaluate non-carcinogenic effects. RfDs are derived from "no-observed-adverse-effect levels" (NOAELs), which represent the highest experimental exposure level at which a particular critical toxic effect is not observed. Cancer slope factors (SF) are used to evaluate potential human carcinogenic risks. A SF is defined as an estimate of the upper 95 percent confidence limit of the slope of the dose-response curve extrapolated to low doses, and is considered to be a measure of the cancer-causing potential of a chemical. RfDs and SFs are provided for both ingestion and inhalation. Toxicity values are obtained from the Integrated Risk Information System (IRIS), the Health Effects Assessment Summary Tables (HEAST), EPA Region III Toxicity criteria, the Public Health Risk Evaluation Database, the Drinking Water Criteria documents, the Ambient Water Quality Criteria documents, the Air Quality Criteria documents, and the Agency for Toxic Substances and Disease Registry (ATSDR) toxicity profiles. Toxicity values for the contaminants of concern in the ground water at the Explosive Washout Lagoons are summarized in Table 1-4.

Table 1-3: Summary of Contaminants of Concern for Ground Water at Site 4

Chemicals	Site Numbers 4, 47 and 67 Flood Gravels	4, 47 and 67 Basalt
TAL Inorganics		
Antimony	▨	▨
Arsenic	▨	ND
Barium	BKGD	BKGD
Beryllium	▨	ND
Calcium	BKGD	BKGD
Chromium	▨	ND
Copper	▨	ND
Iron	ND	BKGD
Lead	▨	BKGD
Magnesium	BKGD	BKGD
Manganese	BKGD	BKGD
Mercury	BKGD	ND
Nickel	▨	ND
Potassium	BKGD	BKGD
Silver	BKGD	ND
Sodium	▨	BKGD
Vanadium	▨	ND
Zinc	▨	BKGD
Cyanide	ND	ND
Selenium	ND	ND
Explosives		
1,3,5-Trinitrobenzene	▨	▨
1,3-Dinitrobenzene	▨	▨
2,4,6-TNT	▨	▨
2,4-DNT	▨	▨
2,6-DNT	▨	ND
HMX	▨	▨
RDX	▨	▨
Nitrobenzene	▨	ND
Tetryl	▨	ND
Other Inorganics		
Nitrate/nitrite	▨	BKGD
Chloride	BKGD	BKGD
Sulfate	BKGD	BKGD
TCL Volatiles		
Trichlorofluoromethane	ND	ND
Toluene	BLK	ND
Benzene	ND	ND
Trichloroethylene	▨	ND
TCL Semivolatiles		
Bis (2-ethylhexyl)phthalate	ND	ND

Notes:

▨ - Selected as a contaminant of concern.

BKGD - Detected but not selected because concentrations were within background levels.

BLK - Detected but not selected because chemical is commonly detected in laboratory blanks; see text for further explanation.

ND - Not Detected

TAL - Target Analyte List

TCL - Target Compound List

Source: HBRA (Dames & Moore, 1992b)

Table 1-4: Summary of Toxicity Criteria for the Contaminants of Concern

Chemical	RfDo (mg/kg/day)	RfDi(a) (mg/kg/day)	SFo	SFi	Source (b)
TAL Inorganics					
Arsenic	3.00E-04	UR	1.75E+00	1.40E+01	1,1,1,1
Beryllium	5.00E-03	ND	4.30E+00	8.40E+00	1,1,1,1
Chromium III	1.00E+00	6.00E-07	ND	ND	1,2,1,1
Chromium IV	5.00E-03	6.00E-07	ND	4.25E-01	1,2,1,1
Copper	3.70E-02	1.00E-02	ND	ND	3,3,1,1
Iron	ND	8.60E-03	ND	ID	3
Lead	IUBK Model	ID	ID	ID	4,4,1,1
Mercury (inorganic)	3.00E-04	9.00E-05	ND	ND	2,2,1,1
Nickel	2.00E-02	UR	ND	8.40E-01	1,1,1,1
Sodium	ID	ID	ID	ID	1,1,1,1
Vanadium	7.00E-03	ND	ND	ND	2,1,1,1
Zinc	2.00E-01	ND	ND	ND	2,1,1,1
1,3,5-Trinitrobenzene	5.00E-05	ND	ND	ND	1,1,1,1
1,3-Dinitrobenzene	1.00E-04	ND	ND	ND	1,1,1,1
2,4,6-TNT	5.00E-04	ND	3.00E-02	ND	1,1,1,1
2,4-DNT	2.00E-03	ND	6.80E-01	ND	5,1,1,1
2,6-DNT	1.00E-03	ND	6.80E-01	ND	5,1,1,1
HMX	5.00E-02	ND	ND	ND	1,1,1,1
RDX	3.00E-03	ND	1.10E-01	ND	1,1,1,1
Nitrobenzene	5.00E-04	6.00E-04	ND	ND	1,2,1,1
Tetryl	1.00E-02	ND	ND	ND	
Other Inorganics					
Nitrate	1.60E+00	ND	ND	ND	1,2,1,1
Nitrite	1.00E-01	ND	ND	ND	6
TCL Volatiles					
Trichloroethylene	UR	UR	1.10E-02	6.00E-03	1,1,7,7
Pesticides/PCBs					
Chlordane	6.00E-05	UR	1.30E+00	1.30E+00	1,1,1,1
Dieldrin	5.00E-05	ND	1.60E+01	1.60E+01	1,1,1,1
DDD	ND	ND	2.40E-01	ND	1,1,1,1
DDE	ND	ND	3.40E-01	ND	1,1,1,1
DDT	5.00E-04	ND	3.40E-01	3.40E-01	1,1,1,1
Endrin	3.00E-04	ND	ND	ND	1,1,1,1
PCB 1260	ND	ND	7.70E+00	ND	1,1,1,1

Notes:
RfDi - inhalation reference dose
RfDo - oral ingestion reference dose
SFi - inhalation slope factor
SFo - oral slope factor
ID - Insufficient Data Available
ND - No Data
UR - Under Review
(a) - Inhalation reference doses were calculated from reference air concentrations (RFCs) assuming that a standard 70 kg human inhales 20 cubic meters of air/day (USEPA, 1989b).
Limitations of these assumptions are discussed in the uncertainty section of the HBRA (Dames & Moore, 1992b).
(b) - Source codes are listed below. The four values shown in this column are the sources for the oral RfD, the inhalation RfD, the oral slope factor, and the inhalation slope factor, respectively.
(1) USEPA, 1991d
(2) USEPA, 1991e
(3) USEPA, 1991g
(4) USEPA, 1991k
(5) Brower, 1992
(6) USEPA, 1990
(7) Ris, 1992

Source: HBRA (Dames & Moore, 1992b)

1.2.3.3 *Exposure Assessment.* Exposure scenarios include a contaminant source, a release or transport mechanism, an exposure pathway by which the contaminant enters the receptor's body, and a potential receptor. Twelve potential exposure pathways were included for the UMDA HBRA:

1. Dermal contact with contaminated soil
2. Inadvertent ingestion of contaminated soil
3. Inhalation of contaminated soil as airborne dust
4. Inhalation of vapors volatilized from soil
5. Ingestion of contaminated ground water
6. Inhalation of volatile contaminants emitted from ground water during showering
7. Dermal contact with contaminated ground water during showering
8. Dermal contact of contaminated ground water during non-showering use
9. Inhalation of vapors during non-showering use of ground water
10. Consumption of game that feeds on vegetation that grows in contaminated soil
11. Consumption of livestock (or their milk) that feed on vegetation growing in contaminated soil and/or that consume contaminated ground water
12. Consumption of crops irrigated by contaminated ground water and/or grown in contaminated soil

In general, each pathway was reviewed for both current and future land use. However, at Site 4, because no current pathways exist, only future land use scenarios were addressed. Receptors for future land use vary with the selected use: residential, industrial, military, agricultural, and recreation. In most cases, the residential scenario was used for future land use because it is the most conservative of the future scenarios.

Pathways were excluded in the risk assessment for individual sites for one of five reasons:

- Sampling was not performed, because the medium and/or contaminant was not considered to be a concern.
- The contaminant source applicable to the specific pathway has been shown not to exist based on sampling results.
- The transport mechanism for the pathway does not exist at the site.
- The receptor does not exist at the site.
- The exposure route cannot exist at the site for other reasons.

In addition to the exclusion of some pathways, other pathways were not quantified because: (1) the exposure resulting from the pathway is much less than that from another analogous pathway; (2) the potential magnitude of the exposure is low; or (3) the probability of the exposure occurring is very low.

The pathways included for quantification of the risk for ground water at the Explosive Washout Lagoons are summarized below:

- Ingestion of contaminated ground water
- Dermal absorption of contaminated ground water during showering
- Consumption of crops irrigated by contaminated ground water and/or grown in contaminated soil

For each quantified pathway, an average daily intake is calculated using a variety of assumptions, i.e, receptor body weight, frequency of exposure, exposure duration, respiration rates, absorption factors, skin surface areas, and ingestion rates. For details regarding which parameters are included in the individual pathways, refer to the Draft HBRA (Dames & Moore, 1992b).

1.2.3.4 Risk Characterization. The risk characterization is conducted by combining the toxicological data with the average daily intakes. Potential incremental cancer risks are calculated by multiplying the daily intake averaged over the receptor's lifetime by the SF. Hazard indices are calculated for non-carcinogenic risks by dividing the average daily intake by the RfD. Carcinogenic risks and non-carcinogenic hazard indexes are calculated for each pathway and then summed to yield the total site risk and hazard index.

The three pathways shown in Section 1.2.3.3 were quantitatively evaluated for the risk assessment at Site 4. The resulting hazard indices and risks are summarized in Table 1-5. For the unconfined aquifer, the total carcinogenic risk is $2x10^{-1}$ and the total non-carcinogenic hazard index is $9x10^{3}$. The basalt aquifer was found to have the same risk.

The risk values reported for consumption of crops are estimated based on both soil and ground water contamination, which resulted in elevated risk estimates when considering only ground water. If crop consumption is eliminated from the total carcinogenic and non-carcinogenic risks, the risk levels decrease. However, even without crop consumption, the site presents risk levels that are outside the acceptable risk range of 10^{-4} to 10^{-6} for carcinogenic risk and greater than 1.0 for the non-carcinogenic hazard index.

Table 1-5: Carcinogenic Risks and Non-Carcinogenic Hazards at Site 4 - Future Residential Land Use Scenario

Pathway No.	Pathway Description	Flood Gravel Risk	Flood Gravel HI	Basalt Risk	Basalt HI
5	Ingestion of Ground Water	3.00E-03	3.00E+01	2.00E-03	6.00E+01
7	Dermal Absorption of Ground Water Contaminants During Showering	2.00E-06	5.00E-06	4.00E-06	1.00E-01
12	Consumption of Crops	2.00E-01	9.00E+03	2.00E-01	9.00E+03
	Totals	2.00E-01	9.00E+03	2.00E-01	9.00E+03
	Total Without Pathway 12	3.00E-03	3.00E+01	2.00E-03	6.00E+01

HI = Hazard Index

Source: Arthur D. Little, Inc.

2.0 Identification and Screening of Technologies

The primary objective of this phase of the FS is to develop an appropriate range of remedial alternatives that will protect human health and the environment by eliminating, reducing, and/or controlling risks posed by each pathway. These alternatives are then assessed in the detailed analysis phase (Section 4.0, Detailed Analysis).

Remedial action objectives that specified the contaminants and media of concern, exposure pathways, and preliminary remediation goals (PRGs) were first developed to enable a range of alternatives to be assembled. The preliminary remediation goals were selected based on the Applicable or Relevant and Appropriate Requirements (ARARs), developed for UMDA by Oak Ridge National Laboratory (1991) and the Human Health Baseline Risk Assessment (Dames & Moore, 1992b).

Once the remedial action objectives were developed, the volume of contaminated ground water was estimated based on the results of the RI. Using the estimated amount of ground water to be remediated and the developed remedial action objectives, potential technologies were identified and screened to eliminate those technologies that were not technically applicable to remediate this site. Applicable process options for the remaining technologies were then identified and evaluated for effectiveness, implementability, and cost. This resulted in the selection of a process option for each technology type.

The detailed description of the technology identification and screening phase is presented in the remaining sections, following the outline provided by EPA in *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA* (EPA, 1988).

2.1 Remedial Action Objectives

Development of the remedial action objectives is the most critical step in the FS process because the objectives are the basis by which the technologies and process options are evaluated. During the development of the remedial action objectives, three items are reviewed: 1) the contaminants that exceed ARARs and risk-based goals in the media of concern; 2) the exposure pathways by which humans or the environment can be exposed to these contaminants; and (3) preliminary remediation goals.

The preliminary remediation goals are concentrations of contaminants for each exposure route that are believed to provide adequate protection of human health and the environment based on preliminary site information. These goals are used to assist in setting parameters for the purpose of evaluating technologies and developing remedial alternatives. For all classes of chemicals, the NCP requires the use of ARARs to set remediation goals (e.g., maximum contaminant levels [MCLs], ambient water quality criteria [AWQC]) when they are available.

When ARARs are not available or are not sufficiently protective because of multiple exposures or multiple contaminants, risk-based remediation goals are derived for non-carcinogenic chemicals. These goals assure that exposures present no appreciable risk of significant adverse effects to individuals, based on a comparison of the exposures to the concentration associated with reliable toxicity information such as the reference dose. Similarly, when ARARs do not exist for carcinogens, remediation goals are set based on the incremental individual lifetime cancer risk range of 10^{-4} to 10^{-6}.

In the development of the remediation goals for Site 4, the EPA requirements for using ARARs, toxicity information for non-carcinogenic contaminants, and the individual lifetime cancer risk range were followed. Because of multiple contaminants and pathways, the most stringent requirement, where appropriate (e.g., zero maximum contaminant level goals were not considered to be appropriate), was selected as the preliminary remedial goal. The preliminary remedial goals were then combined to ensure that if the site was remediated to these levels, the total individual lifetime cancer risk would fall within the range of 10^{-4} to 10^{-6} and the non-carcinogenic effects to individuals would present no appreciable risk.

2.1.1 Media and Contaminants of Concern

Contamination has been identified in both the unconfined aquifer and the second confined aquifer at the Explosive Washout Lagoons. The spacial extent of contamination in the two aquifers is significantly different, therefore, the nature and extent of contamination is discussed separately for each aquifer.

The unconfined aquifer consists of the alluvium and weathered flowtop of the Elephant Mountain member (Section 1.2.1.2.3, Hydrogeology). The RI (Dames & Moore, 1992b) presented the Cemented Basalt Gravel/Weathered Bedrock (CBG/WB) and the underlying gravel as part of the unconfined aquifer; however, additional studies (Dames & Moore, 1993) have shown that the CBG/WB is the Elephant Mountain basalt layer.

Twenty-one potential contaminants of concern (Table 2-1) were identified in the HBRA, including 10 metals, 9 explosives, nitrate/nitrite, and trichloroethylene. Each of these potential contaminants of concern was compared to the chemical-specific ARARs and risk-based cleanup goals developed in Section 2.1.3.1. Based on this comparison, six explosives were determined to be contaminants of concern and carried through the FS.

- 1,3,5-TNB
- 1,3-DNB
- 2,4,6-TNT
- 2,4-DNT
- 2,6-DNT
- RDX

Table 2-1: Selection of Contaminants of Concern for the FS

Chemicals of Concern From HBRA		Comments
TAL Inorganics		
Antimony	☐	Was detected twice; however, both detections were below the background concentration of 8 µg/L and the MCL of 6 µg/L.
Arsenic	☐	Was detected 16 times; however, all detections were below or at the background concentration of 15 µg/L and below the MCL of 50 µg/L.
Beryllium	☐	Was detected one time below the MCL of 4 µg/L.
Chromium	☐	Was detected eight times; however, all detections were below the MCL of 100 µg/L .
Copper	☐	Was detected five times; however, all detections were below or at the background concentration of 15 µg/L and below the MCL of 1,300 µg/L.
Lead	☐	Was detected eight times; however, all detections were below or at the background concentration of 13 µg/L and below the MCL of 15 µg/L.
Nickel	☐	Was detected two times; however, all detections were below the MCL of 100 µg/L.
Sodium	☐	Was detected 26 times; however, all detections were below the background concentration of 100,000 µg/L.
Vanadium	☐	Was detected 12 times; however, all detections were below or at the background concentration of 100 µg/L and below the risk-based cleanup level of 260 µg/L.
Zinc	☐	Was detected three times; however, all detections were below the Oregon MCL of 5,000 µg/L.
Explosives		
1,3,5-TNB	▨	Was detected 27 times, and several detections were above the risk-based cleanup level of 18 µg/L.
1,3-DNB	▨	Was detected 13 times, and several detections were above the risk-based cleanup level of 4 µg/L.

Table 2-1: Selection of Contaminants of Concern for the FS (continued)

Chemicals of Concern From HBRA		**Comments**
2,4,6-TNT	▨	Was detected 20 times, and several detections were above the risk-based cleanup level of 2.8 µg/L.
2,4-DNT	▨	Was detected 16 times, and several detections were above the CRL of 0.6 µg/L.
2,6-DNT	▨	Was detected one time, and the detection was above the CRL of 1.2 µg/L.
HMX	☐	Was detected 22 times; however, all detections were below the risk-based cleanup level of 1,800 µg/L.
RDX	▨	Was detected 68 times, and several detections were above the CRL of 2.1 µg/L.
NB	☐	Was detected three times; however, all detections were below the risk-based cleanup level of 20 µg/L.
Tetryl	☐	Was detected one time; however, the detection was below the risk-based cleanup level of 400 µg/L.
Other Inorganics		
Nitrate/Nitrite	☐	Was detected 90 times; however, all but two detections were below the background concentration of 54,000 µg/L. The two detections above the background concentration were located outside the explosive plume.
TCL Volatiles		
Trichloroethylene	☐	Was detected one time; however, the detection was below the MCL of 5 µg/L.

Notes:
Shaded blocks indicate that the compound was retained as a contaminant of concern in the FS.
MCL – Maximum Contaminant Level
CRL – Certified Reporting Limit
TAL – Target Analyte List
TCL – Target Compound List

Source: Arthur D. Little, Inc.

These six compounds represent the majority of the total risk (approximately 84%) and total hazard index (approximately 95%) from the site (without Pathway 12, ingestion of crops). The 15 other potential contaminants of concern from the risk assessment were eliminated because they were not found at Site 4 in concentrations that exceeded preliminary remediation goals (PRGs) (Table 2-1).

In the second confined aquifer only RDX and 2,4-DNT were detected above cleanup levels; the highest RDX concentration detected was found in Well 4-9 which is located southeast of the source area. RDX was the only contaminant detected above its criteria at this location: 1,100 µg/L in October 1990 and 4,700 µg/L in February 1991. Because no contamination was found in the first confined aquifer, the Army Environmental Center has suspected that either drilling activities or possibly slight well leakage may be causing the contamination measured in the second confined aquifer. Additional time-series sampling was conducted in Wells 4-8 and 4-9 to measure the extent of contamination, and downhole video logging was conducted to investigate the integrity of the wells. The results of this work are currently being reviewed, though first indications are that second aquifer contamination did arise from a small amount of well leakage from the alluvial aquifer, and that no remedial action other than removal of the wells is needed. The Army is preparing to conduct this work in consultation with the regulatory agencies.

Descriptions of the sampling and ground water findings for Site 4 are provided in Section 1.4, Nature and Extent of Contamination.

2.1.2 Exposure Pathways

The probability of current exposure of human receptors to the ground water contaminants of concern at Site 4 is considered low because of access restrictions and was, therefore, not evaluated. Because of UMDA's inclusion in the BRAC Program, the probability of future exposure of human receptors is considered high based on the probability that UMDA property will eventually be vacated by the Army and become available for residential or industrial use. Three future land use scenarios were evaluated:

- Residential
- Light Industrial
- Military

For each land use scenario, two exposure pathways were evaluated that may potentially apply to the ground water at Site 4. Each pathway was not applicable to all three of the land use scenarios. The pathways were:

- Ingestion of contaminated ground water
- Dermal absorption of ground water contaminants during showering

Crop ingestion was also considered a pathway in the HBRA and estimated to present carcinogenic and non-carcinogenic risks; however, EPA, with concurrence from ODEQ and the Army, has determined that the crop ingestion pathway is not a likely exposure pathway at Site 4 due to the slope and sandy nature of the soils, which generally make the site unusable for agriculture. Therefore, this pathway has not been included in the development of preliminary remediation goals.

The residential land use scenario is applicable to both pathways and it is also the most conservative scenario of the three future land use options for exposure of human receptors to the ground water contaminants at Site 4. Therefore, the remaining discussion of this FS will be based on the residential land use scenario.

A summary of potential carcinogenic risks and non-carcinogenic hazards for these exposure pathways is provided in Table 1-5 in Section 1.2.3.4, Risk Characterization.

2.1.3 Applicable or Relevant and Appropriate Requirements

The selection of ARARs is dependent on the hazardous substances present at the site, the site characteristics and location, and the actions selected for a remedy. Therefore, ARARs are developed in three categories:

- Chemical-specific
- Location-specific
- Action-specific

Chemical-specific ARARs are health- or risk-based concentration limits set for specific hazardous substances, pollutants, or contaminants. Location-specific ARARs address such circumstances as the presence of wetlands on the site or the location of the 100-year floodplain. Action-specific ARARs control or restrict particular types of remedial actions as alternatives for cleanup.

2.1.3.1 Chemical-Specific ARARs and Risk-Based Remedial Goals. In developing chemical-specific ARARs, both federal and state regulations were considered (Table 2-2). In addition, because there are no chemical-specific ARARs for explosives, risk-based remedial goals were calculated for a hazard index of 1 for noncarcinogens and an incremental risk of $1x10^{-6}$ for carcinogens. These risk-based remedial goals are not considered ARARs but they are presented here so that all potential preliminary remediation goals can be shown together.

Federal ARARs

Safe Drinking Water Act. In the National Contingency Plan (NCP), EPA states the preference for Safe Drinking Water Act (SDWA) maximum contaminant levels (MCLs) and non-zero maximum contaminant level goals (MCLGs) or other health-based

Table 2-2: Chemical-Specific Applicable or Relevant and Appropriate Requirements (ARARs) Site 4, Umatilla Explosive Washout Lagoons Ground Water

Authority	Requirement	Status	Requirement Synopsis	Action to be Taken to Attain ARAR
State Regulatory Requirements	Oregon Groundwater Quality Protection Regulations	Applicable	Maintains and preserves the quality of the state's ground water, these regulations establish reference levels and guidance levels for certain contaminants.	The Numerical Groundwater Quality Reference Levels and Guidance Levels will be used to determine the level of remedial action necessary to restore contaminated ground water for human consumption.
	Oregon Drinking Water Regulations	Relevant and Appropriate	Establishes drinking water MCLs for a number of organic and inorganic contaminants.	Remediation may be needed to achieve MCLs in ground water.
	Oregon Hazardous Substance Remedial Action Rules	Applicable	Establishes standards and processes to be used for the determination of the degree of cleanup necessary to assure protection of the present and future public health, safety, and welfare and the environment in the event of a release of a hazardous substance.	The rules will be used to determine the level and type of cleanup necessary to achieve background levels or the lowest concentration that is both feasible and protective.
Federal Nonregulatory Advisories and Guidance Requirements	U.S. EPA Risk Reference Doses (RfDs)	To Be Considered	Protects against noncarcinogenic effects from exposure to contamination.	RfDs will be considered to assess health risks from contaminants at the site.

Table 2-2: Chemical-Specific Applicable or Relevant and Appropriate Requirements (ARARs) (continued)

Authority	Requirement	Status	Requirement Synopsis	Action to be Taken to Attain ARAR
	U.S. EPA Carcinogen Assessment Group (CAG) Potency Factors	To Be Considered	Presents CAG Potency Factors to compute the incremental cancer risk from exposure to site contaminants.	CAG potency factors will be considered to assess health risks from contaminants at the site.
	U.S. EPA Health Advisories (HA) and Acceptable Daily Intakes (ADIs)	To Be Considered	Provides guidelines for chemicals that may be intermittently encountered in public water supply systems.	HAs and ADIs will be considered for remedial actions involving ground water monitoring, recovery, and treatment, especially for contaminants that are not regulated under the SDWA.
	Health Effects Assessments (HEAs)	To Be Considered	Presents toxicity data for specific chemicals for use in public health assessments.	HEAs will be considered to assess health risks from contaminants at the site. Also applies to direct emissions, emissions during excavations, and emissions from leachate or ground water treatment limits.
Federal Regulatory Requirements	Safe Drinking Water Act (SDWA) Maximum Contaminant Levels (MCLs); 40 CFR 141.11-141.16, 141.61, 141.62	Relevant and Appropriate	Enforceable standards for specific toxic compounds for public drinking water systems. MCLs reflect both health factors and technical and economic feasibility of removing the contaminant from the water supply.	Remediation may be needed to achieve SDWA MCLs for ground water.

Table 2-2: Chemical-Specific Applicable or Relevant and Appropriate Requirements (ARARs) (continued)

Authority	Requirement	Status	Requirement Synopsis	Action to be Taken to Attain ARAR
	SDWA MCLGs; 40 CFR 141.50-141.51	Relevant and Appropriate	Nonenforceable health goals for public water systems. The U.S. EPA has promulgated MCLGs for specific contaminants and proposed MCLGs for others (50 FR 46936).	If SDWA MCLs do not provide sufficient protection to human health and environmental receptors, MCLGs will be considered in establishing health-based standards.
	National Secondary Drinking Water Standards; 40 CFR Part 143	Relevant and Appropriate	Nonenforceable health goals for public water systems.	Remediation may be needed to restore water quality to meet these goals.
	Resource Conservation and Recovery Act (RCRA) Maximum Concentration Limits; 40 CFR 264.94	Relevant and Appropriate	Standards for 14 toxic compounds, primarily toxic metals and pesticides, adopted as part of RCRA ground water protection standards.	RCRA MCLs may be considered as ground water protection standards for contaminated ground water.

Source: Arthur D. Little, Inc.

standards, criteria, or guidance for the cleanup of Class I and II ground water at CERCLA sites. Ground water is classified according to its potential for use, including as drinking water.

The EPA Ground Water Protection Strategy designates three categories of ground water:

- Class I: Special Ground Waters - Waters that are highly vulnerable to contamination and are either irreplaceable or ecologically vital sources of drinking water.

- Class II: Current and Potential Sources of Drinking Water and Waters Having Other Beneficial Use - All other ground waters that are currently used or are potentially available for drinking water or other beneficial use.

- Class III: Ground Water Not Considered Potential Sources of Drinking Water and of Limited Beneficial Use - Waters that are highly saline (i.e., they have total dissolved solids over 10,000 mg/l) or are otherwise contaminated beyond levels that allow cleanup using methods reasonably employed in public treatment systems. These ground waters also must not be able to migrate to Class I or II ground waters or to have a discharge to surface water that could cause degradation.

The goal of EPA's approach to contaminated ground water cleanup is to return usable ground water to its beneficial use, within a reasonable time frame, given the particular circumstances of the site. The EPA guidance on ground water classification, although not an ARAR until promulgated, should be used in determining whether the ground water at a site falls within Class I, II, or III. This can then be used in determining which cleanup standards may be relevant and appropriate. Restoration time periods vary depending on the use classification of the ground water and may range from one year to several decades. The alluvial ground water at UMDA Site 4 is currently used to supply crop irrigation water in the nearby area while the basalt aquifer supplies drinking water for the UMDA site; therefore, they are categorized as Class I.

Under the SDWA, a number of chemical-specific standards pertaining to water quality were established in 40 CFR 141 as the National Primary Drinking Water Standards (NPDWS). These regulations are applicable to public water systems that have at least 15 service connections or that regularly serve an average of at least 25 people 60 days of the year. NPDWS include MCLs and MCLGs. The MCLs are enforceable standards that take into consideration human health effects, available treatment technologies, and costs of treatment. MCLGs are specifically health-based standards that disregard cost or treatment feasibility and are not legally enforceable. MCLs are legally applicable to water "at the tap," but are not legally applicable to cleanup of ground water. However, they may be considered as relevant and appropriate at UMDA where ground water is currently used as drinking water.

Seven Target Analyte List (TAL) inorganic contaminants present at Umatilla Site 4 have promulgated or proposed MCLs/MCLGs set by EPA. These values will be considered relevant and appropriate for cleanup of these contaminants in ground water. They are listed in Table 2-3 with all ARARs and other remedial goals for the site.

Resource Conservation and Recovery Act

In addition to SDWA MCLs and MCLGs, another potential set of ARARs are found in the regulations promulgated under the Resource Conservation and Recovery Act (RCRA). Under RCRA, a small number of chemical-specific standards were established for releases from solid waste management units. Concentration limits for 14 toxic compounds, found in 40 CFR 264.94, are known as RCRA maximum concentration limits, or RCRA MCLs. These standards have been adopted as part of RCRA ground water protection standards. The RCRA MCLs apply to regulated units subject to permitting (landfills, surface impoundments, waste piles, and land treatment units) that received RCRA hazardous waste after July 26, 1982. If a comparison of indicator concentrations from background and downgradient wells shows a statistically significant increase, a ground water protection standard is established for all hazardous constituents. The baseline protection standard is the background level of the constituent, or one of the 14 RCRA MCLs, whichever is higher. Many of these ground water protection standards are equal to MCLs established under the SDWA. Since the ground water at Site 4 is currently used as a source of drinking water, the RCRA MCLs are considered relevant but not appropriate, and the SDWA MCLs/MCLGs should be considered as the relevant and appropriate cleanup standard.

State ARARs - Ground Water

Oregon Water Cleanup Standards. The Oregon Hazardous Substance Remedial Action Rules (Oregon Administrative Rules [OAR], Chapter 340, Division 122) provides a process for determining contaminant cleanup levels on a site-specific basis. The Oregon Department of Environmental Quality (ODEQ) has indicated that this process should be considered an ARAR. The process is implemented as follows:

- In the event of a release of a hazardous substance, the environment shall be restored to background level (i.e., the concentration naturally occurring prior to any release from the facility) [OAR 340-122-040(2)(a)].
- When attaining background level is not feasible, the acceptable cleanup level in ground water shall be the lowest concentration level that satisfies both the "protection" and "feasibility" requirements in OAR 340-122-090(1). The party responsible for the contaminated site is responsible for demonstrating the non-feasibility of attaining background level.

Of the seven specific types of explosive contaminants of concern at Site 4, all are considered not naturally occurring. Therefore, the background concentration would be essentially zero or, for practical purposes, below detection limits. If a remedial alternative proposed in this FS cannot achieve background or below detection limits, a risk assessment approach must be used to demonstrate that the action achieves the lowest cleanup level that protects human health and the environment, using the criteria set forth in OAR 340-122-090.

In addition to these requirements, Oregon's state goal (ORS 468B.155) to "prevent contamination of (its) ground water resource while striving to conserve and restore this resource and to maintain the high quality of Oregon's groundwater resource for present and future users" will be included as a TBC criteria.

Oregon Safe Drinking Water Regulations. The State of Oregon, through the Oregon Drinking Water Regulations (OAR Chapter 333, Division 61) implements the Oregon Drinking Water Quality Act of 1981. These rules set forth maximum contaminant levels for organic and inorganic chemicals drinking water. Like the federal SDWA MCLs, the state MCLs are not legally applicable to cleanup of ground water. However, they should be considered as relevant and appropriate standards for the cleanup of contaminated ground water at UMDA where the ground water is used for domestic water supply. The state drinking water chemical-specific ARARs for the cleanup of contaminated ground water at UMDA are listed in Table 2-3.

State ARARs

Oregon Ground Water Quality Protection Regulations. The Oregon Ground Water Quality Protection Regulations (OAR 340-40) establish that it is the state's policy to protect all ground waters "from pollution that could impair existing or potential beneficial uses for which the natural water quality of the ground water is adequate" and to maintain and reserve the highest possible water quality. The Numerical Groundwater Quality Reference Levels and Guidance Levels OAR 340-40-080 are used by the Department of Environmental Quality (DEQ) in determining the level of remedial action necessary to restore contaminated ground water for human consumption. The Numerical Groundwater Quality Reference and Guidance Levels for arsenic, chromium, copper, lead, and zinc are identical to the Oregon and federal drinking water MCLs and therefore would be relevant and appropriate for remedial action concentration limits for Umatilla.

Umatilla is located in the Lower Umatilla Basin, which is a state-designated ground water management area. Such areas are required to comply with the interim standards for maximum measurable levels of contaminants in ground water set forth in OAR 340-30-090. These standards are also identical to the federal and Oregon drinking water MCLs for arsenic, chromium, and lead. The Oregon Groundwater Quality Protection chemical-specific ARARs are in Table 2-3.

Table 2-3: Chemical-Specific ARARs and Remedial Goals for Cleanup of Contaminated Gro

Contaminant of Concern from RA	Chemical-Specific ARARs SDWA MCL/MCLG (a) (mg/L)	Proposed SDWA MCL/MCLG (mg/L)	Oregon Drinking Water Regulations MCL (f) (mg/L)	Oregon Numerical Ground Water Quality Reference Levels (h) (mg/L)
TAL Inorganics:				
Antimony	0.006/0.006 (b)	–/– (c)	–	–
Arsenic	0.05/-	–/–	0.05	0.05 (i)
Beryllium	0.004/0.004 (b)	–/– (d)	–	–
Chromium	0.1/0.01	–/–	0.05	0.05 (i)
Copper	–/1.3 (f)	–/–	1 (g)	1.0 (j)
Lead	0.015 (e)/0	–/–	0.05	0.05 (i)
Nickel	0.1/0.1	–/–	–	–
Sodium	–/–	–/–	–	–
Vanadium	–/–	–/–	–	–
Zinc	–/–	–/–	5.0 (g)	5.0 (j)
Explosives:				
1,3,5-TNB	–/–	–/–	–	–
1,3-DNB	–/–	–/–	–	–
2,4,6-TNT	–/–	–/–	–	–
2,4-DNT	–/–	–/–	–	–
2,6-DNT	–/–	–/–	–	–
HMX	–/–	–/–	–	–
RDX	–/–	–/–	–	–
NB	–/–	–/–	–	–
Tetryl	–/–	–/–	–	–
Other Inorganics:				
Nitrate/Nitrite	10	–/–	–	10
TCL Volatiles:				
Trichloroethylene	0.005/-	–/–	–	–

Notes:

Shaded concentration indicates that it was selected as the cleanup level (see Section 2.1.5 for how these cleanup levels were selec

(a) Safe Drinking Water Act (SDWA) National Primary Drinking Water Regulations (40 CFR 141).

(b) The effective date is January 17, 1994.

(c) The proposed MCL/MCLG was 0.01 or 0.005/0.003.

(d) The proposed MCL/MCLG was 0.001/0.

(e) Action level for treatment techniques (40 CFR 141.80).

(f) OAR 333-61.

(g) Contaminant level for secondary contaminants (reasonable goals).

(h) Oregon Groundwater Quality Protection Regulations (OAR 340-40-080).

(i) Reference level.

(j) Guidance level.

(k) Interim Standards for Maximum Measurable Levels of Contaminants in Ground Water (OAR 340-40-090).

(l) Based on achieving a residential HI of 1.

(m) Based on achieving a residential carcinogenic risk of 1x10E-6.

(n) Based on highest value found in Non-Source Area Wells (Section 14.0 of the RI).

(o) The explosive compounds are not found in nature therefore for quantitation purposes background has been set to the CRL.

(p) Army Certified Reporting Limit.

Source: Arthur D. Little, Inc.

aminated Ground Water (mg/L)

n Numerical und Water y Reference vels (h) mg/L)	Oregon Maximum Measurable Levels (k) (mg/L)	Lifetime Adult Health Advisory (mg/L)	Remedial Goals		
			Risk-Based (mg/L)	Background (mg/L)	CRLs (p) (mg/L)
–	–	0.003	0.02 (l)	0.008	0.003
.05 (i)	0.05	0.05	0.00005 (m)	0.015	0.00025
–	–		0.00002 (m)	–	0.005
.05 (i)	0.05	0.1	0.18 (l)	0.006	0.006
1.0 (	–	–	1.0 (e)/1.35 (l)	0.015	0.0081
.05 (i)	0.05	–	–	0.013	0.00126
–	–	0.1	0.73 (l)	–	0.0343
–	–	–	–	100	0.5
–	–	0.02	0.26 (l)	0.1	0.00382
5.0 (j)	–	2	5.0 (c)/7.3 (l)	0.04	0.0211
–	–	–	0.018 (l)	– (o)	0.000626
–	–	0.001	0.004 (l)	– (o)	0.000519
–	–	0.002	0.0028 (m)	– (o)	0.000588
–	–	–	0.0001 (m)	– (o)	0.000612
–	–	–	0.0001 (m)	– (o)	0.00115
–	–	0.4	1.82 (l)	– (o)	0.00165
–	–	0.002	0.0008 (m)	– (o)	0.00211
–	–	–	0.02 (l)	– (o)	0.00107
–	–	–	0.4 (l)	– (o)	0.000566
10	–	–	58	54 (n)	0.001
–	–	–	0.0004	– (o)	0.001

p levels were selected).

set to the CRL.

Other Guidance to Be Considered

National Secondary Drinking Water Standards. Also promulgated under the SDWA are the National Secondary Drinking Water Standards. These regulations control contaminants in drinking water that primarily affect the aesthetic qualities relating to the public acceptance of drinking water. At considerably higher concentrations of these contaminants, health implications can also exist as well as aesthetic degradation. These regulations are not federally enforceable, but are intended as guidelines for the states.

Copper and zinc, potential contaminants of concern at Site 4, have secondary maximum contaminant levels (SMCLs) listed in 40 CFR 143. SMCLs are "to be considered" (TBC) guidance for cleanup of contaminated ground water since the ground water is a source of drinking water.

Risk-Based Remedial Goals

In the absence of ARARs, risk-based remedial goals may be used based on EPA risk assessment guidance. Risk-based cleanup criteria were calculated for ground water at Site 4. The ground water cleanup concentrations are presented in Table 2-3. The cleanup criteria is the concentration of each compound present in any media that does not pose a carcinogenic risk greater than 10^{-6} or a hazard index greater than 1 for all applicable exposure scenarios. It must be kept in mind that these criteria depend upon the Site 4 exposure scenario and are therefore not applicable at other sites.

Carcinogenic and non-carcinogenic risks are calculated by initially calculating an exposure factor (E). The exposure factors for each media are given by:

Ground Water Ingestion:

$$E\ (\mathrm{L/kg/day}) = \frac{IGR \times BAF \times EF \times ED}{BW \times AP \times 365\ \mathrm{days/yr}} \qquad \text{(eq. 2.1.3-1)}$$

where: AP = averaging period (years)
BAF = bioavailability factor (unitless)
BW = body weight (kg)
ED = exposure duration (years)
EF = exposure frequency (days/year)
IGR = ingestion rate (L/day for water, or mg/day for soil)

Ground Water Dermal Contact:

$$E\ (\mathrm{kg/kg/day}) = \frac{DR \times SA \times ABS \times EF \times ED \times (10^{-6})\ \mathrm{kg/mg}}{BW \times AP \times 365\ \mathrm{days/yr}}$$

(eq. 2.1.3-2)

where: DR = deposition rate (mg/sq. cm.)
SA = skin surface area per time (sq. cm/day)
ABS = absorption factor (fraction)

Once an exposure factor has been determined for each medium the average daily dose (ADD) is calculated by multiplying the exposure concentration (C) by the exposure factor:

$$\mathbf{ADD(mg/kg/day) = C \times E} \qquad \text{(eq. 2.1.3-3)}$$

The non-carcinogenic hazard index (HI) is then calculated by dividing the ADD by the chemical reference dose (RfD):

$$\mathbf{HI = ADD/RfD} \qquad \text{(eq. 2.1.3-4)}$$

The incremental risk (IR) associated with cancer is calculated by multiplying the ADD by the chemical cancer potency factor (CPF):

$$\mathbf{IR = ADD \times CPF} \qquad \text{(eq. 2.1.3-5)}$$

Using these equations the concentrations (C) associated with a hazard index of 1, and a carcinogenic risk of 10^{-6} are respectively given by:

$$\mathbf{C = (HI \times RfD)/E} \qquad \text{(eq. 2.1.3-6)}$$
$$\mathbf{C = IR/(E \times CPF)} \qquad \text{(eq. 2.1.3-7)}$$

The sum of the two exposure factors for the media was used in each calculation. The exposure factors used are:

	Non-carcinogenic	Carcinogenic
Ground Water	6.4×10^{-2}	9.4×10^{-3}

The RfDs and CPFs are chemical specific. For details regarding their values and any additional risk calculations refer to the Human Health Baseline Risk Assessment (Dames & Moore, 1992b).

2.1.3.2 Location-Specific ARARs. Location-specific ARARs set restrictions on remedial action activities depending upon the characteristics of a site and/or its immediate environs. These ARARs are contained in a number of federal statutes and regulations. In addition, the state of Oregon has requirements that may apply in a given situation. The information regarding the characteristics of UMDA was obtained from the RI Report (Dames & Moore, 1992a). Table 2-4 lists the regulations that may be considered ARARs for UMDA.

Table 2-4: Selected Location-Specific Applicable or Relevant and Appropriate Requirements (ARARs)

Location	Requirement	Status	Requirement Synopsis	Prerequisite(s)
Wetland	Executive Order 11990; Protection of Wetlands (40 CFR 6 Appendix A); 40 CFR 6.302 (a)	Applicable	Must take action to avoid adverse impact, minimize potential harm, and to preserve and enhance wetlands to the extent possible.	Wetlands as defined 40 CFR 6, Appendix A §4; action of federal agencies involving construction of facilities or management of property in wetland areas.
	40 CFR 6, Appendix A	Applicable	Federal agencies shall incorporate floodplain management goals and wetlands protection considerations in its planning, regulatory, and decision-making process.	
	40 CFR 6, Appendix A	Applicable	Federal agencies should avoid new construction in wetlands areas.	
	Clean Water Act §404; 40 CFR 230.10; 33 CFR 320-330; ORS 196.105 et seq; OAR §141-85-005 et seq.	Applicable	Prohibits discharge of dredge or fill material into wetlands without permit.	Wetlands as defined in U.S. Army Corps of Engineers and EPA regulations.
	Clean Water Act §404(b)(1)	Applicable	Provides for the enhancement, restoration, or creation of alternate wetlands.	Unavoidable adverse impacts on wetlands.

Table 2-4: Selected Location-Specific Applicable or Relevant and Appropriate Requirements (ARARs) (continued)

Location	Requirement	Status	Requirement Synopsis	Prerequisite(s)
Critical habitat upon which an endangered or threatened species depends.	Endangered Species Act of 1973 (16 USC 1531 et seq.); 50 CFR 402; Fish and Wildlife Coordination Act (16 USC 661 et seq.); ORS 496.004; ORS 496.172 et seq.; ORS 498.026; ORS 498.04	Applicable	Must take action to conserve endangered or threatened species; must not destroy or adversely modify critical habitat. Must consult with Department of Interior, FWS, and state personnel required to ascertain that proposed actions will not affect any listed species.	Determination of presence of federal or Oregon listed endangered or threatened species.
Within area where action may cause irreparable harm, loss, or destruction of significant artifacts.	Archaeological and Historic Preservation Act (16 USC 469a-1)	Applicable	Must take action to recover and preserve artifacts.	Dam construction or alteration of terrain that threatens significant scientific, prehistorical historical, or archeological data.

Source: Oak Ridge National Laboratory, 1991

In addition to the ARARs discussed in each of the following sections, consideration should also be given to the local planning requisites in both Morrow and Umatilla Counties. Oregon law mandates that each county and community develop, and have approved by the state, a comprehensive land use plan which must take into consideration many of the same concerns addressed in this discussion. Consultation with the appropriate county officials and cognizance of their land use plans and goals would no doubt increase the efficacy of any actions proposed or taken at UMDA.

Caves, Salt-dome Formations, Salt-bed Formations, and Underground Mines

These formulations often trigger restrictions in locating new construction such as landfills and incinerators. The bedrock under UMDA and the surrounding area consists of basalt laid down by lava flows during the Miocene Period. This is capped by a mixture of Pleistocene alluvial deposits, including clays, sands, silts, gravels, and some boulders. There are sedimentary interbeds between the lava flows and this type of rock also has tunnels and occasionally "lava holes." However, there are no indications of caves, salt-dome formations, salt bed formations or underground mines on the site, nor would such features normally be expected with a structural bedrock of basaltic lava flows. Thus no ARARs were triggered for this category.

Faults

UMDA is surrounded by four structural features: the Service Anticline on the east, an anticline on the west, the Dalles-Umatilla Syncline to the north, and a monocline to the south. This Service Anticline runs north to south and is faulted on both its east and west limbs. There are active Holocene faults approximately 50 to 80 miles north of the site, near the Hanford Nuclear Reservation in Washington State. There is also a suspected active Holocene fault approximately 70 miles southeast of the depot near LeGrand, Oregon. However, none of the faulting associated with the Service Anticline is documented or believed to have been displaced during the Holocene period, nor is it considered active.

Because of the surrounding area's history of low seismicity, UMDA activities would comply with the RCRA seismic requirements of 40 CFR § 264.18 since CFR §264.18(a) stipulates that all facilities that are located within political jurisdictions other than those listed in Appendix VI are assumed to be in compliance for location of new treatment, storage, or disposal (TSD) facilities. Oregon is not listed in the Appendix.

Wilderness Areas, Wildlife Refuges, and Scenic Rivers

There are no designated wilderness areas within UMDA, or in its immediate vicinity. Neither the Columbia River nor the Umatilla River, both of which lie within 3 miles of the depot, have been designated as scenic rivers. There are, however, three wildlife refuges in very close proximity to the depot: Cold Spring National Wildlife Refuge at 15 miles, Umatilla National Wildlife Refuge at 8 miles, and Irrigon State Wildlife Refuge at 2 miles. The latter of these refuges, Irrigon, is protected under state law and is considered a sensitive environment. It is one of the primary wetlands in this region and supports a major waterfowl wintering habitat.

There would be no ARARs triggered for on-site actions because the UMDA itself is not located within a refuge. However, the proximity of Irrigon State Wildlife Refuge (2 miles) and its potential hydrological connection to UMDA cautions careful analysis of any actions that might impact that system.

Wetland and Floodplains

The Columbia River is largely dam controlled, thus, eliminating most concerns with flooding hazards. Information available indicates that UMDA is not located within 100- or 500-year floodplains and, therefore, no ARARs were triggered for this category (ORNL, 1991).

There are a number of wetlands in the immediate area of UMDA, to the east, west, and south. Those associated with the Umatilla River on the east come within at least one mile of the site. Additionally, the wetlands located near the northwest corner of the depot extend to the boundary of the UMDA. Wetlands located to the west of UMDA are associated with Irrigon State Wildlife Refuge and those to the south are 2.5 to 3.5 miles from the depot. Since none of the identified wetlands are within the boundaries of Site 4 or UMDA, wetland requirements are not considered to be ARARs.

Rare, Threatened, or Endangered Species

The UMDA installation is part of the critical winter range of both the bald eagle (*Haliaeetus leucocephalus*) and the golden eagle (*Aquila chrystaetos*). The peregrine falcon (*Falco peregrinus*), another federally endangered species, has been sighted in the vicinity of UMDA, and the installation is considered part of its critical habitat. One of three small habitats along the Columbia River where the long-billed curlew (*Numenius Americanus*) still breeds is located on the installation. The species is on the federal "Candidate" list. No federal or state threatened or endangered plants have been identified at UMDA.

Any action that would affect any endangered or threatened species, or adversely impact a species' critical habitat, would be subject to the ARARs outlined in Table 2-4. There are no additional state threatened or endangered species known to inhabit UMDA.

Artifacts and Historical and Archeological Sites

There are two known historic buildings at UMDA, the headquarters building and the firehouse building. There are also two potential archeological resources at UMDA that have been tentatively identified as a portion of the Oregon Trail and a prehistoric site. These sites are not within the boundaries of Site 4 and none of the activities at Site 4 will affect these locations; therefore, these regulations are not considered to be ARARs.

2.1.3.3 Action-Specific ARARs. Action-specific ARARs (Table 2-5) are usually technology- or activity-based requirements or limitations on actions taken with respect to hazardous wastes. These requirements are triggered by the particular remedial activities that are selected to accomplish a remedy. On-site CERCLA response actions must only comply with the substantive requirements of regulations, and not the administrative requirements [CERCLA §121(e)]. Since the UMDA Federal Facility Agreement defines the UMDA installation as the Site, none of the permitting or other administrative requirements of RCRA, the Clean Air Act (CAA), etc., are considered as ARARs.

For the remedial alternatives (UV/oxidation and carbon adsorption) considered for the cleanup of the ground water at the Explosive Washout Lagoon only those regulations concerning the discharge to ground water and the transportation of hazardous waste off site are considered ARARs. None of the alternatives have air discharges.

Water Discharges

The Clean Water Act (CWA) has distinct regulatory features that include site-specific pollutant limitations and performance standards that are applied primarily for protection of surface water quality. The CWA does not have specific technology design and operating requirements that can be linked to specific remedial technologies. However, some remedial actions at Site 4 will result in discharges to surface and/or ground water, and thus will have to comply with certain provisions of the CWA.

Federal ARARs

CERCLA §121 states that hazardous substances, pollutants, or contaminants left on site at the conclusion of the remedial action shall attain federal water quality criteria where they are relevant and appropriate under the circumstances of a release or threatened release. This determination is to be based on the designated or potential use of the receiving water, the media affected, the purposes of the criteria, and current information. Thus, for any discharge to waters designated as a public water supply (such as the ground water at Site 4) resulting from any remedial action, the federal drinking water standards in 40 CFR 141 would be relevant and appropriate. Water quality criteria as stand-alone criteria are not relevant and appropriate in selecting cleanup levels in ground water, since consumption of contaminated fish is not a concern. However, a water quality criteria adjusted to reflect only exposure from drinking the water may be useful in selecting a cleanup level.

Although a permit is not required for any on-site discharges to water, any discharge of treated water resulting from a remedial action must still meet the intent of the federal standards, which means the discharged effluent must be monitored to ensure compliance with the MCLs.

Table 2-5: Action-Specific Applicable or Relevant and Appropriate Regulations (ARARs) Site 4, Umatilla Depot Activity Explosive Washout Lagoons Ground Water

Authority	Requirement	Status	Requirement Synopsis	Action to be Taken to Attain ARAR
State Regulatory Requirements	Oregon Hazardous Substance Remedial Action Rules	Applicable	Establishes standards and process to be used for the determination of degree of cleanup necessary to assure protection of the present and future public health, safety, and welfare and the environment in the event of a release of a hazardous substance.	The rules will be used to determine the level and type of cleanup necessary to achieve background levels or the lowest concentration that is both feasible and protective.
	Construction and Use of Waste Disposal Wells or Other Underground Injection Activities	Applicable	Regulations preserve the quality of the ground water from contamination by discharge from injection wells and other subsurface waste disposal of hazardous and other wastes. Regulates proper location, construction, and use of injection wells and other subsurface disposal systems to prevent ground water contamination.	Any remedial design involving underground injection of liquids will be located, constructed, and operated in compliance with SDWA MCLs.

Table 2-5: Site 4 Action-Specific ARARs, Umatilla Washout Lagoons Ground Water (continued)

Authority	Requirement	Status	Requirement Synopsis	Action to be Taken to Attain ARAR
Nonregulatory Criteria Advisories and Guidance to be Considered	EPA Interim Policy for Planning and Implementing CERCLA Response Actions. Proposed Rule, 50 FR 45933 (November 5, 1985)	To Be Considered	Discusses the need to consider treatment, recycling, and reuse before off-site land disposal is used. Prohibits use of a RCRA facility for off-site management of Superfund hazardous substances if the facility has significant RCRA violations.	This policy will be considered prior to any off-site management of hazardous substances.
Federal Regulatory Requirements	RCRA Generator Requirements; 40 CFR 262	Applicable and/or Relevant and Appropriate	These regulations set forth manifest, labeling, and accumulation limit requirements for generators of hazardous waste.	Any hazardous waste, including any hazardous treatment residual, shipped off-site for treatment or disposal must be manifested and must be managed on-site according to 40 CFR 262.
	Underground Injection Control Program; 40 CFR 144	Applicable	Leach fields utilized by generators of hazardous waste must be managed in accordance with operating and monitoring requirements.	The disposal leach field will be designed, operated, and monitored in accordance with 40 CFR 144 requirements for a class V well.

Table 2-5: Site 4 Action-Specific ARARs, Umatilla Washout Lagoons Ground Water (continued)

Authority	Requirement	Status	Requirement Synopsis	Action to be Taken to Attain ARAR
	RCRA Hazardous Waste Determination Requirements 40 CFR 261	Applicable and/or Relevant and Appropriate	These regulations set forth the criteria by which a waste is determined to be hazardous.	Any waste, including any treatment residuals, will be evaluated using these criteria to determine whether or not they are a hazardous waste.
	RCRA Transporter Requirements 40 CFR 263	Applicable and/or Relevant and Appropriate	These regulations set forth packaging and labeling requirements for transporters of hazardous waste.	Any hazardous waste, including any hazardous treatment residual, shipped offsite for treatment or disposal must be transported in accordance with 40 CFR 263.
	RCRA Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities; 40 CFR 264	Applicable and/or Relevant and Appropriate	This regulation establishes minimum national standards for management of hazardous wastes, for owners and operators of facilities that treat, store, or dispose of hazardous waste.	Remediation of hazardous waste may involve various forms of treatment, storage or disposal (TSD). The design and operating standards for TSD units will be met 40 CFR 264.190–264.192 (tank systems); 40 CFR 264.221 (surface impoundments); 40 CFR 264.251 (waste piles); 40 CFR 264.273 (land treatment units); 40 CFR 264.343-264.345 (incinerators); 40 CFR 264.601 (miscellaneous treatment units).

Table 2-5: Site 4 Action-Specific ARARs, Umatilla Washout Lagoons Ground Water (continued)

Authority	Requirement	Status	Requirement Synopsis	Action to be Taken to Attain ARAR
	RCRA Land Disposal Restrictions; 40 CFR Part 268	Applicable and/or Relevant and Appropriate	Prohibits the disposal of RCRA hazardous waste in the land unless treatment standards are met or a treatability variance is obtained.	Remedial activities that involve the movement of excavated materials to a new location and placement in or on land or that generate residual hazardous wastes will trigger land disposal restrictions (LDR). Any wastes subject to LDR must be treated using best demonstrated available treatment technologies (BDAT) for each hazardous constituent in each listed waste.

Source: Arthur D. Little, Inc.

State ARAR - Oregon Water Cleanup Standards

The Oregon Hazardous Waste Remedial Action Act provides a process for determining contaminant cleanup levels on a site-specific basis. The Oregon Department of Environmental Quality (ODEQ) has indicated that this process should be considered an ARAR. The process is implemented as follows:

- In the event of a release of a hazardous substance, the environment shall be restored to background level (i.e., the concentration naturally occurring prior to any release from the facility) [OAR 340-122-040(2)(a)].
- When attaining background level is not feasible, the acceptable cleanup level in ground water shall be the lowest concentration level that satisfies both the "protection" and "feasibility" requirements in OAR 340-122-090(1). The party responsible for the contaminated site is responsible for demonstrating the non-feasibility of attaining background level.

Of the six specific types of explosive contaminants of concern at Site 4, all are obviously considered to be not naturally occurring. Therefore, the background concentration would be essentially zero or, for practical purposes, below detection limits. If a remedial alternative proposed in this FS cannot achieve background or below detection limits, a risk assessment approach must be used to demonstrate that the action achieves the lowest cleanup level that protects human health and the environment.

State ARAR - Oregon Water Quality Standards

State policy for the management of the quality of public waters is set forth in OAR Chapter 340, Division 41 - Oregon Water Quality Standards. These rules establish water quality standards for the various river basins in Oregon. Umatilla Basin water quality standards are found in OAR 340-41-645. With regard to toxic substances, any remedial action will have to be designed so as to not introduce toxic substances above natural background levels in amounts, concentrations, or combinations that may be harmful or may bioaccumulate to levels that adversely affect public health or safety, the environment, or other designated uses. However, the EPA Water Quality Criteria, set forth in Table 20 of the Oregon Water Quality Criteria, does not set limits for any of the contaminants of concern at Site 4.

State ARAR - Underground Injection

OAR Chapter 340, Division 44 is also an applicable ARAR for discharges to ground water at Site 4. These regulations will influence the location, construction, and use of any underground injection wells so as to prevent contamination of the underground sources of drinking water. Specifically, OAR 340-44-015(4)(d) specifies that underground injection activities that allow the movement of fluids into an underground source of drinking water (e.g., the ground water at Site 4) may not violate any SDWA MCLs. If the water is reinjected within the capture zone, Oregon DEQ may waive the requirement for compliance with MCL. However, Oregon DEQ has stated that they may not approve the reinjection of water contaminated above background levels outside of the capture zone, at Site 4.

Hazardous Waste

CERCLA § 121 establishes a preference for remedial actions involving treatment that permanently and significantly reduce the volume, toxicity, or mobility of the hazardous substances, pollutants, and contaminants at the site. RCRA requirements for treatment of hazardous wastes apply at a CERCLA site only if the waste is a RCRA listed or characteristic waste and the CERCLA activity constitutes treatment of RCRA hazardous waste, as defined under RCRA.

As discussed for the Washout Lagoons soils (CH2M Hill, 1992) the lagoons soils are not a listed or characteristic hazardous waste. Because of this and also because ground water is not considered a waste, the Site 4 ground water is not a RCRA hazardous waste.

Treatment residuals from the ground water remediation (e.g., carbon from adsorption systems) would not be considered a hazardous waste as long as they do not exhibit hazardous characteristics. Specifically, the spent GAC would not be a RCRA hazardous waste as long as the total explosive concentration is below 10% and the GAC passes the TCLP for DNT.

Transportation

RCRA hazardous wastes transported off the sitewould be subject to the full RCRA requirements, as applicable. RCRA hazardous wastes and waste residues shipped off site must be packaged, labeled, and transported in accordance with the requirements of 40 CFR 262.32 and 49 CFR 172. Transporters must comply with the requirements of 40 CFR 263. These regulations are applicable ARARs for off-site transport.

Removal of Special Restrictions on Land Disposal

Hazardous waste or hazardous waste residue may be subject to restrictions on land disposal under 40 CFR 268. Any hazardous waste residue resulting from any remedial action destined for off-site land disposal must meet applicable treatability standards prior to land disposal of a characteristic waste from a granular activated carbon system.

2.1.4 Remedial Action Objectives

Under CERCLA, the Army, with concurrence with EPA and DEQ, must undertake remedial actions that are protective of human health and the environment. In addition, Section 121 of CERCLA establishes several other statutory requirements and preferences, including:

- A requirement that the remedial action, when complete, must comply with all federal and more-stringent state environmental standards, requirements, criteria, or limitations, unless a waiver is invoked.

- A requirement that a remedial action be selected that is cost effective and that utilizes permanent solutions and alternative treatment technologies or resource recovery technologies to the maximum extent practicable.

- A preference for remedies in which treatment that permanently and significantly reduces the volume, toxicity, or mobility of the hazardous substance is a principal element.

The remedial alternatives developed and analyzed in this FS are consistent with these Congressional mandates.

Based on the preliminary information relating to types of contamination and media of concern and potential exposure pathways, remedial action objectives were developed to aid in the development and screening of alternatives. These remedial action objectives mitigate existing and future potential threats to public health and the environment from the ground water under the Explosive Washout Lagoons. The objectives are:

- Return ground water to its beneficial use.

- Prevent ingestion of and dermal contact with ground water having carcinogens in excess of ARARs and a total excess cancer risk (for all contaminants) greater than the risk range of 10^{-4} to 10^{-6}.

- Prevent ingestion of and dermal contact with ground water having non-carcinogens in excess of ARARs and a hazard index (for all contaminants) greater than 1 for each compound.

2.1.5 Preliminary Remediation Goals for Ground Water

Preliminary remediation ground water goals were established for the seven contaminants of concern (See Table 2-6) identified in the HBRA (Dames & Moore, 1992b) that were found to pose an unacceptable risk to public health. These goals were set based on the ARARs, the risk-based goals, background concentrations, and detection limits.

Because the ground water under the site has been categorized as a Class I aquifer, MCLs and non-zero MCLGs established under the Safe Drinking Water Act are ARARs. Preliminary remedial goals for known, probable, and possible carcinogenic compounds (Classes A, B, and C respectively) were established to protect against potential carcinogenic effects and to conform with the ARARs. Because the MCLGs for Class A and B compounds are set at zero and are thus not suitable for use as preliminary remedial

Table 2-6: Preliminary Remedial Goals for Ground Water

Carcinogenic Contaminants of Concern	Preliminary Remedial Goal (µg/L)	Basis	Level of Risk	Hazard Index
Explosives:				
1,3,5-TNB	1.8 (a)	Risk-Based	–	1
1,3-DNB	4.0	Risk-Based	–	1
2,4,6-TNT	2.8	Risk-Based	1.0E-06	–
2,4-DNT	0.6	CRL	4.0E-06	–
2,6-DNT	1.2	CRL	5.0E-06	–
RDX	2.1	CRL	3.0E-06	–
Nitrite	54,000	Background	–	–
	Total Excess Risk		1.3E-05	2

Notes:

(a) Uncertainty surrounds the toxicity of 1,3,5-TNB. The Army is currently performing toxicity studies on 1,3,5-TNB and the PRG may be revised based on the results of this study during the five-year review.

CRL – Certified Reporting Limit

Source: Arthur D. Little, Inc.

goals, MCLs and proposed MCLs were selected as the interim cleanup levels for these classes of compounds. Because the MCLGs for the Class C compounds are greater than zero and can readily be confirmed, MCLGs and proposed MCLGs were selected as the preliminary remedial goals for Class C compounds.

Preliminary remedial goals for Class D and E compounds (not classified and with no evidence of carcinogenicity) were established to protect against potential non-carcinogenic effects and to conform with the ARARs. Because the MCLGs for these classes are greater than zero and can readily be confirmed, MCLGs and proposed MCLGs were selected as the preliminary remedial goals for Classes D and E compounds.

In situations where a promulgated Oregon standard is more stringent than values established under the Safe Drinking Water Act, the state standard was used as the preliminary remedial goal. In the absence of an MCLG, MCL, proposed MCLG, proposed MCL, state standard, or other suitable criteria to be considered (e.g., health advisory, state guideline), a preliminary remedial goal was derived for each compound having carcinogenic potential (Classes A, B, and C compounds) based on a 10^{-6} excess cancer risk level per compound considering ingestion of ground water from domestic water usage.

In the absence of the above standards and criteria, preliminary remedial goals for all other compounds (Classes D and E) were established based on an acceptable level to which the human population, including sensitive subgroups, may be exposed without adverse effect during a lifetime or part of a lifetime. This incorporated an adequate margin of safety (hazard index = 1) considering the ingestion of ground water. If a value described by any of the above methods was not capable of being detected with good precision and accuracy, then the practical quantification limit was used as appropriate for the preliminary remedial goal.

Ground water pathways other than ingestion (dermal adsorption and volatile inhalation) were evaluated qualitatively in the human health risk assessment and found not to represent a significant risk to human health in comparison to the risk posed by ingestion (Section 2.1.2, Exposure Pathways). Because in the qualitative analysis the other pathways were found not to be significant, only the ingestion pathway was used to calculate the preliminary remedial goals for ground water.

2.2 General Response Actions

This section describes broad categories of remedial measures, called general response actions, that could be used to achieve the remedial action objectives described in Section 2.1, Remedial Action Objectives. A particular general response action might be able to be accomplished by any of several technology types. In turn, a single technology type might encompass several more specific methodologies called process options. For example, "treatment" would be a general response action, "thermal treatment" would be a technology type, and "incineration" or "thermal desorption" would be two examples of process options.

The following general response actions considered alone or in combination could potentially achieve the remedial action objectives:

- No Action
- Institutional Controls
- Containment
- Treatment, In Situ
- Treatment, Ex Situ

The NCP requires that "No Action" be included among the general response actions evaluated in every FS [40 CFR 300.430(e)(6)]. No Action means that no response to contamination is made, activities previously initiated are abandoned, and no further active human intervention occurs to limit exposure to the site. However, natural attenuation of the contaminated media will occur over time through dilution, biological degradation, and/or abiotic degradation. The No Action response provides a baseline for comparison to the other remedial response actions.

Institutional controls include measures such as site access restrictions (e.g., legal restrictions and/or fencing) and land use restrictions (e.g., specifying future use such as residential, or light industrial). Although potential exposure can be reduced by these means, the contaminated media are not directly remediated. As with the No Action scenario, natural recovery of contaminated media might occur.

Containment actions will control or reduce migration of the contaminated materials into the surrounding environment. They might also isolate the contaminated media to reduce the possibility of exposure by direct contact. These actions may involve the use of physical barriers to block a contaminant migration pathway.

The treatment actions may include the use of biological, physical-chemical, or thermal processes to significantly reduce the toxicity, solubility, mobility, or volume of wastes. In some cases, treatment technologies are used to change the properties of the waste so as to limit the solubility or mobility of the contaminants or to prepare the waste for further treatment. Many treatment options will generate residuals or byproducts that must be disposed of with or without further treatment. The residuals or byproducts might or might not be hazardous.

2.3 Ground Water Modeling and Volume Calculations

In order to satisfy several of the goals of the FS at the Umatilla facility, ground water contaminant transport modeling was conducted. Specifically, the subset of remedial feasibility goals examined were:

- Determination of the current extent of contamination and concentration gradients
- A "No Action" scenario to determine how long it would take the contaminant plume to naturally attenuate to the 10^{-4} and 10^{-6} risk based cleanup criteria for the contaminants of concern
- Development of a conceptual remedial extraction system for cleaning up the contaminants of concern to the 10^{-4} and 10^{-6} risk based cleanup criteria, over a period of approximately 10 and 30 years

To accomplish these goals, a ground water contaminant transport model was developed using existing field data, laboratory data, and UMDA facility operational records. It should be noted that this model is intended to provide engineering estimates and qualitative analysis and is not intended to be used to prepare the remedial design. The remedial design effort will have to prepare a more detailed model to accurately determine the number and location of the extraction wells and location of the infiltration galley. The model prepared for the FS will be the starting point of the remedial design activity and a meeting will be held with the personnel responsible for the remedial design to transfer the experience developed in the FS and the FS model data files.

2.3.1 Conceptual Model

Starting in approximately 1955, the washout lagoons were used for disposal of wastewater with high concentrations of explosive compounds. These lagoons received wastewater from the Explosives Washout Plant for approximately 10 years at a total flow volume of approximately 85 million gallons. After this time, the lagoons were no longer used; and the lagoons gradually began to revegetate and dry.

During the operational period of the lagoons, the wastewater disposed to the lagoons pooled within the impoundments and partially evaporated and infiltrated into the underlying highly permeable soils. The explosive compounds, which were dissolved in the wastewater, also migrated into the subsurface along with the wastewater. After the lagoon stopped receiving wastewater, rainwater continued to provide a driving force for transporting the explosives to the subsurface, but at a rate 3,600 times lower than during the wastewater disposal period. This estimate is based on a comparison between wastewater disposal rates and natural recharge due to precipitation (Section 1.2.1.2.6 Meteorology).

The lithology and geohydrology of the Umatilla site, described in detail in the RI (Dames & Moore, 1992a) and RI addendum (Dames & Moore, 1993), briefly consists of approximately 20 to 125 feet of unsaturated alluvial sands and gravels underlain by about 15 feet of saturated clean sands and gravels that grade to 15 to 20 feet of silty and clayey sands and gravels that lie on the Elephant Mountain Member basalt layer. To the north of the Explosive Washout Lagoons, the saturated aquifer appears to become more silty and clayey whereas to the south, the aquifer is composed primarily of gravels. The long-term ground water monitoring studies indicate that, historically, the water levels fluctuate in the uppermost aquifer due to agricultural pumping. These water level changes cause ground water gradient in the area of the lagoons to vary from about 4×10^{-4} to 2×10^{-3} ft/ft and the direction to vary from south/southeast to northwest.

Since the upper part of the unconfined aquifer (the top 15 feet) possesses a relatively high hydraulic conductivity (i.e., about 2000 ft/day) in comparison to the lower stratigraphic unit (i.e., about 0.1 ft/day), the contaminants are assumed, for the most part, to have been restricted to the upper part of the aquifer. As the contaminants traveled through the aquifer they have undergone dispersion, adsorption to the soil, degradation, and advection. In this manner, they formed the contaminant plume that spreads within the ground water aquifer.

Beginning in about 1981, several geohydrologic and contaminant studies were conducted at UMDA that indicated that RDX, 2,4,6-TNT, 1,3,5-TNB, 1,3-DNB, 2,4-DNT, and 2,6-DNT had contaminated the unconfined aquifer and that RDX and 2,4,6-TNT had formed distinct contaminant plumes. The other explosive contaminants were found at significantly lower concentrations. RDX and 2,4,6-TNT have migrated respectively at least 3,000 feet (MW 4-24) and 1,500 feet (MW 4-6) downgradient of the disposal lagoons. The migration distances were calculated based on the distance from the lagoons to the furthest well where a detection of the contaminant was observed (see Figures 2-7 and 2-8).

Laboratory partition studies (Dames & Moore, 1992a) for RDX and 2,4,6-TNT indicate that these compounds have partitioning coefficients in ground water respectively of 0.21 and 1.0. Assuming a bulk density (Dames & Moore, 1992a) of 1.5 gm/cm^3 and an effective porosity of 0.2, retardation factors of 2.6 and 8.5 for RDX and TNT respectively are calculated. This indicates that the contaminants should migrate between about two and nine times slower than unreactive ground water. An effective porosity of 0.2 was selected based on studies by McWhorter and Sunda (1977) where they found the arithmetic average for specific yield or effective porosity of 0.2 for gravel aquifers. The effective porosity presented in the RI (0.45) was not used because there appears to be a mistake in the calculation, and the effective porosity shown in the RI is probably the total porosity.

Ground water and soil contaminant studies (Dames & Moore, 1992a) have also shown that other contaminants are present in the soil and ground water but are reasonably represented by the chemical properties of 2,4,6-TNT and RDX. These two explosives were selected because they are present in the highest concentrations and represent the most mobil, (RDX) and least mobil, (TNT) contaminants.

One of the main assumptions of the ground water and contaminant transport modeling is that a complex site geology, hydrology, and contaminant scenario can be simplified and effectively modeled. The effectiveness of the modeling effort can usually be determined based on the calibration of the model and the data quality needs. The UMDA site poses a difficult challenge to modeling because of a number of factors, including the unknown contaminant source loading rate, the wide variations in hydraulic conductivity over very short distances, the potential for interconnection and fracture flow across several geologic units, the scarcity of historical water level measurements, and the patchwork of contaminant concentration data.

In order to manage the variability and complexity, the ground water model was conducted over a large section of the aquifer. As a result, the model averages the aquifer features and contaminant data in order to generate responsive and approximate solutions. In this manner, the effect of individual spatial variations is minimized without compromising the overall accuracy and benefit of the model. In addition, recent studies (Dames & Moore, 1993) have shown that the gravel aquifer does not appear to have a significant hydraulic connection with the Rattlesnake Ridge Interbed. This is evident by the lack of contamination in this layer and the wide variation in piezometric elevations between these two units, which suggests hydraulic separation.

2.3.2 Model Development

To assess the contaminant transport environment of the Umatilla site, a two-dimensional contaminant transport model was developed. By developing a contaminant transport model of the site, the historical movement of contaminants at the site was simulated and remedial scenarios, including a ground water extraction system and a "no action" scenario, were tested. The site area is relatively large and the available site characterization data are limited. Based on this limitation, information needs, and the known complexity of the ground water direction and gradient situation, the model does not account for all the intricacies of the site, but rather focuses on the broad, average site conditions. Using average site conditions was appropriate for this model because its objective was to develop engineering estimates for the FS and qualitative information from which alternatives could be developed and analyzed.

The model selected for the site was the USGS's Method of Characteristics (MOC) two-dimensional contaminant transport model. The model was developed more than 10 years ago and has been applied to a wide number of contaminated sites with success and is one of the most commonly used contaminant transport models. The model is two-dimensional and accounts for saturated flow, recharge, well pumping, transient conditions, a variety of boundary conditions, contaminant decay, and adsorption. These model characteristics were sufficient to meet the modeling characterization and informational output requirements. The base case model set, which represents the best estimate of the UMDA site conditions, is presented in the following paragraphs. Table 2-7 lists the model input parameters for the various scenarios. A sensitivity analysis was conducted for the parameters of transmissivity, ground water gradient, dispersivity, and effective porosity, and these results are presented in Section 2.3.4.

Model Grid

The model grid developed for the site consisted of an inner 20 by 20 grid for contaminant transport and an outer 40 by 40 grid for ground water flow. The model dimensions were expanded to a 20 by 30 inner and 40 by 50 outer dimension for some contaminant transport simulations. The smaller of the model grids is shown in Figure 2-1.

Aquifer Thickness

The layer thickness for the unconfined alluvial aquifer was assumed to be a constant at 15 feet throughout the modeled area. Well logs from the RI report and subsequent information provided in the Intermediate Alluvial Well Installation Report (Dames & Moore, 1993) indicate that the thickness of this aquifer varies from about 10 feet to 30 feet and averages approximately 15-feet. Due to the relatively uniform thickness of the aquifer, a constant thickness was used rather than a variable thickness. Further refinement of the thickness could be performed in the design phase.

For the modeling study, the assumption was made that the unconfined aquifer was limited to the 15 foot alluvial gravel unit. Only the alluvial gravel unit (hydraulic conductivity about 2,000 ft/day) was considered because the underlying clays, silts and Elephant Member Basalt (hydraulic conductivity of about 0.1 ft/day) appears to be, on average, relatively impermeable in comparison. The assumption has, therefore, been made that most of the contaminants are traveling approximately horizontally in the alluvial aquifer. Contaminant sampling has shown that some contaminants are present below the alluvial aquifer in the weathered portion of the Elephant Mountain Member, but this contamination is limited in extent and and concentration.

Hydraulic Conductivity

The hydraulic conductivity of the uppermost aquifer has been evaluated by slug testing and three aquifer tests. The results indicate that the hydraulic conductivity of the unconfined aquifer ranges from 2 ft/day to more than 2,700 ft/day. Due to the large variability in hydraulic conductivity, a variable hydraulic conductivity model was developed. The model hydraulic conductivity and corresponding transmissivity variations are shown in Figures 2-2 and 2-3, along with the field data for specific monitoring wells. As shown in these figures, a large area of the site covered by the model has not been investigated so a conservative uniform value was chosen for these nodes of 2,300 ft/day.

Table 2-7: Contaminant Transport Model Input Parameters

Scenario	Grid X Spacing (ft)	Grid Y Spacing (ft)	Maximum Number of Particles	Number of Particles Per Node	Effective Porosity (%)	Dispersivity (ft)	Storage Coefficient
Historical and Well Extraction Contaminant Scenarios	400	400	6400	9	20	15	0.1
RDX, No Action PRG, Cleanup Level	2000	9999	6400	9	20	3000	0.1
RDX, No Action 1.00E-4 Cleanup Level	4000	4000	6400	9	20	500	0.1
TNT, No Action PRG, Cleanup Level	2000	9999	6400	9	20	3000	0.1
TNT, No Action 1.00E-4 Cleanup Level	1000	1000	6400	9	20	500	0.1

Table 2-7: Contaminant Transport Model Input Parameters (cont.)

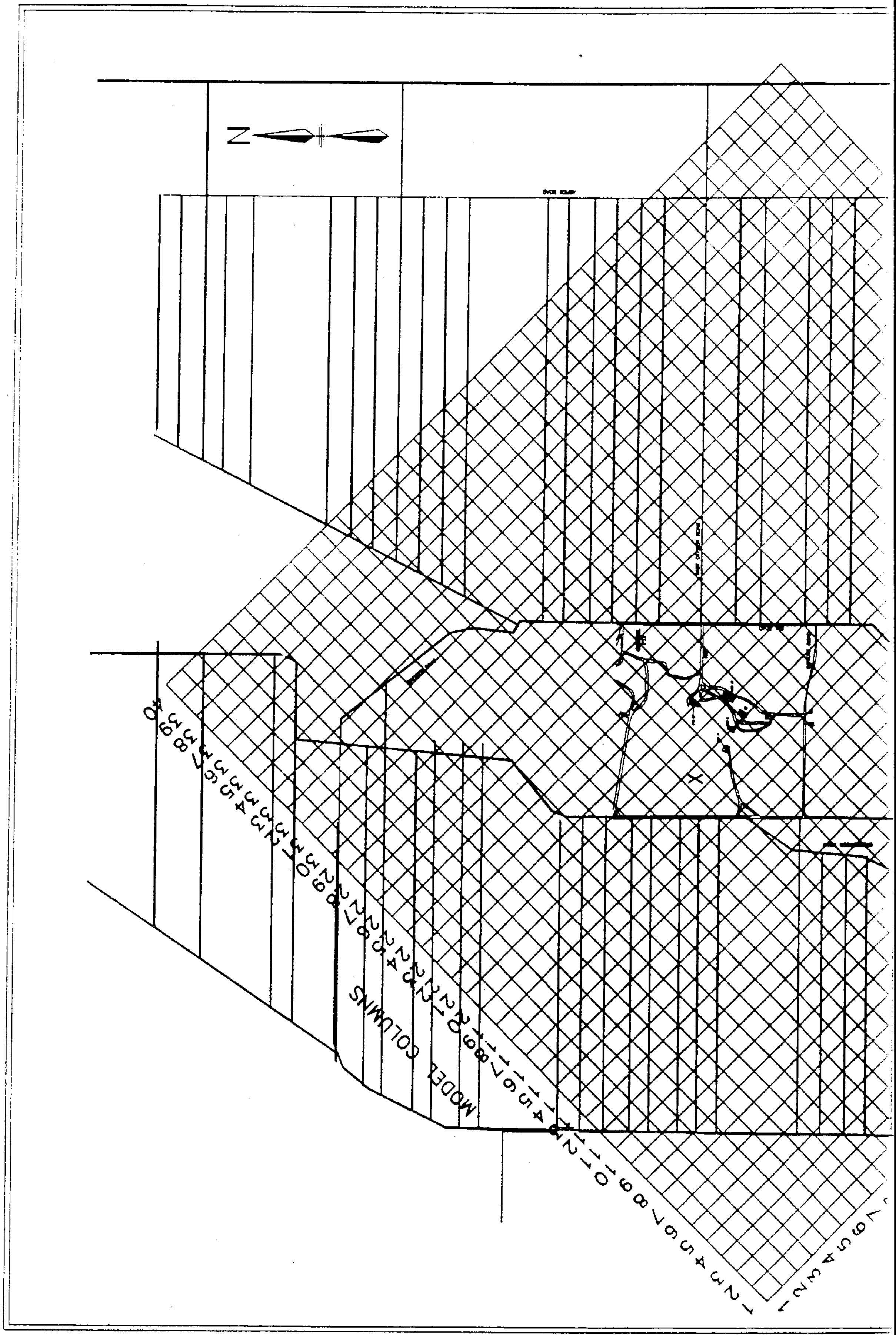
Scenario	Ratio of Transverse To Longitudinal Dispersivity	Transmissivity (sq. ft./sec)	Aquifer Thickness (ft)	Aquifer Distributed Recharge (sq.ft./sec)	Number of Columns	Number of Rows	Distribution Coeffiecient
Historical and Well Extraction Contaminant Scenarios	0.1	see Figure 2-3	15	0	40	40	0.21 or 1.0 accordingly
RDX, No Action PRG, Cleanup Level	0.1	0.4	15	0	40	50	0.21
RDX, No Action 1.00E-4 Cleanup Level	0.1	0.4	15	0	40	50	0.21
TNT, No Action PRG, Cleanup Level	0.1	0.4	15	0	40	50	1
TNT, No Action 1.00E-4 Cleanup Level	0.1	0.4	15	0	40	50	1

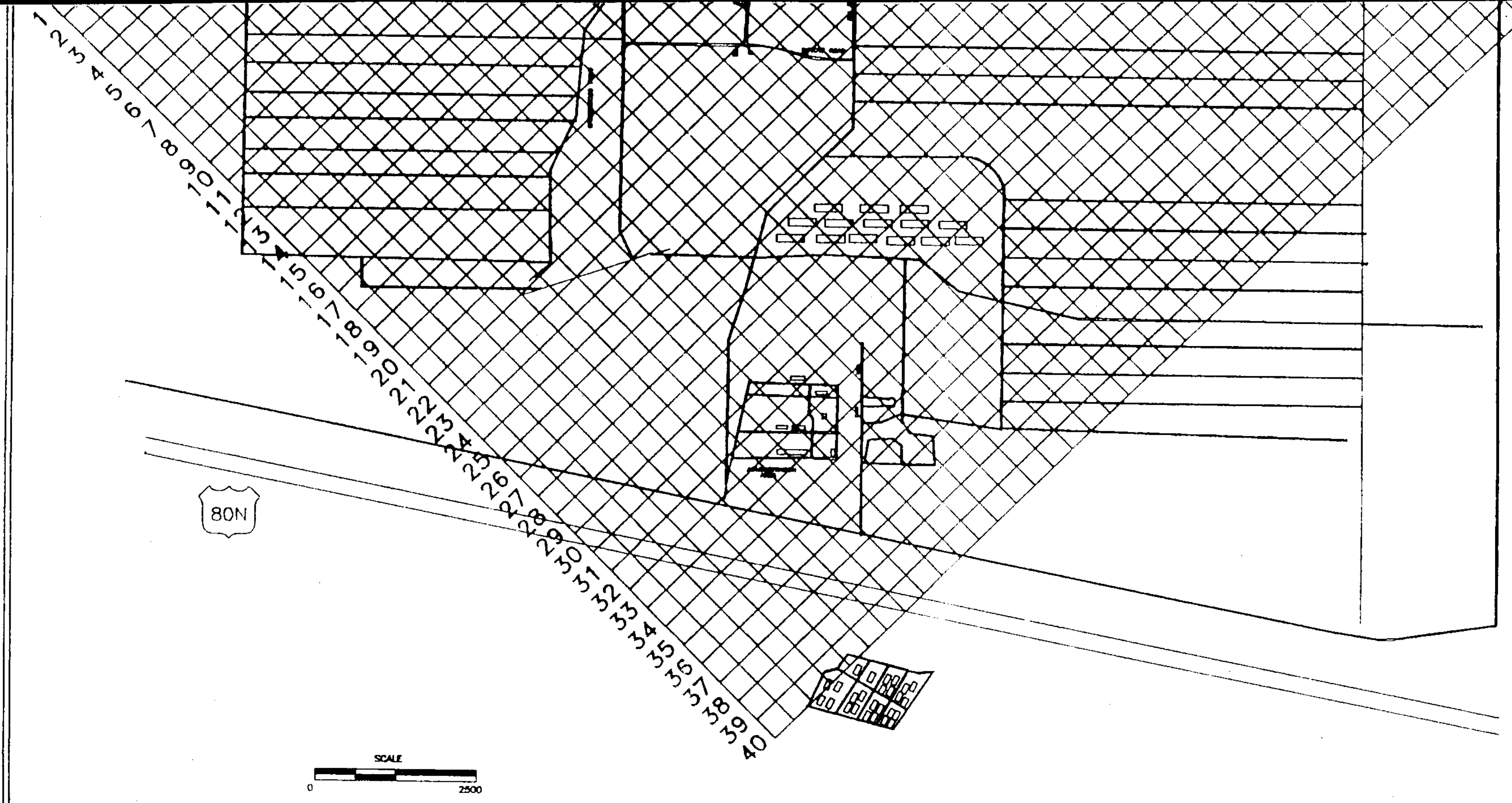
Table 2-7: Contaminant Transport Model Input Parameters (cont.)

Scenario	Contaminant Concentration Discharged to Ground Water (μg/L)	Historic Lagoon Discharge Rate (cubic ft/sec) (a)
Historical and Well Extraction Contaminant Scenarios	4000 (TNT) and 3000 (RDX)	-0.036
RDX, No Action PRG, Cleanup Level	3000	-0.036
RDX, No Action 1.00E-4 Cleanup Level	3000	-0.036
TNT, No Action PRG, Cleanup Level	4000	-0.036
TNT, No Action 1.00E-4 Cleanup Level	4000	-0.036

(a) This column presents the estimated discharge rate from the explosive washout building from 1955 to 1965. Rate was calculated based on the discharge of 85 million gallons over 10 years.

Source: Arthur D. Little, Inc.

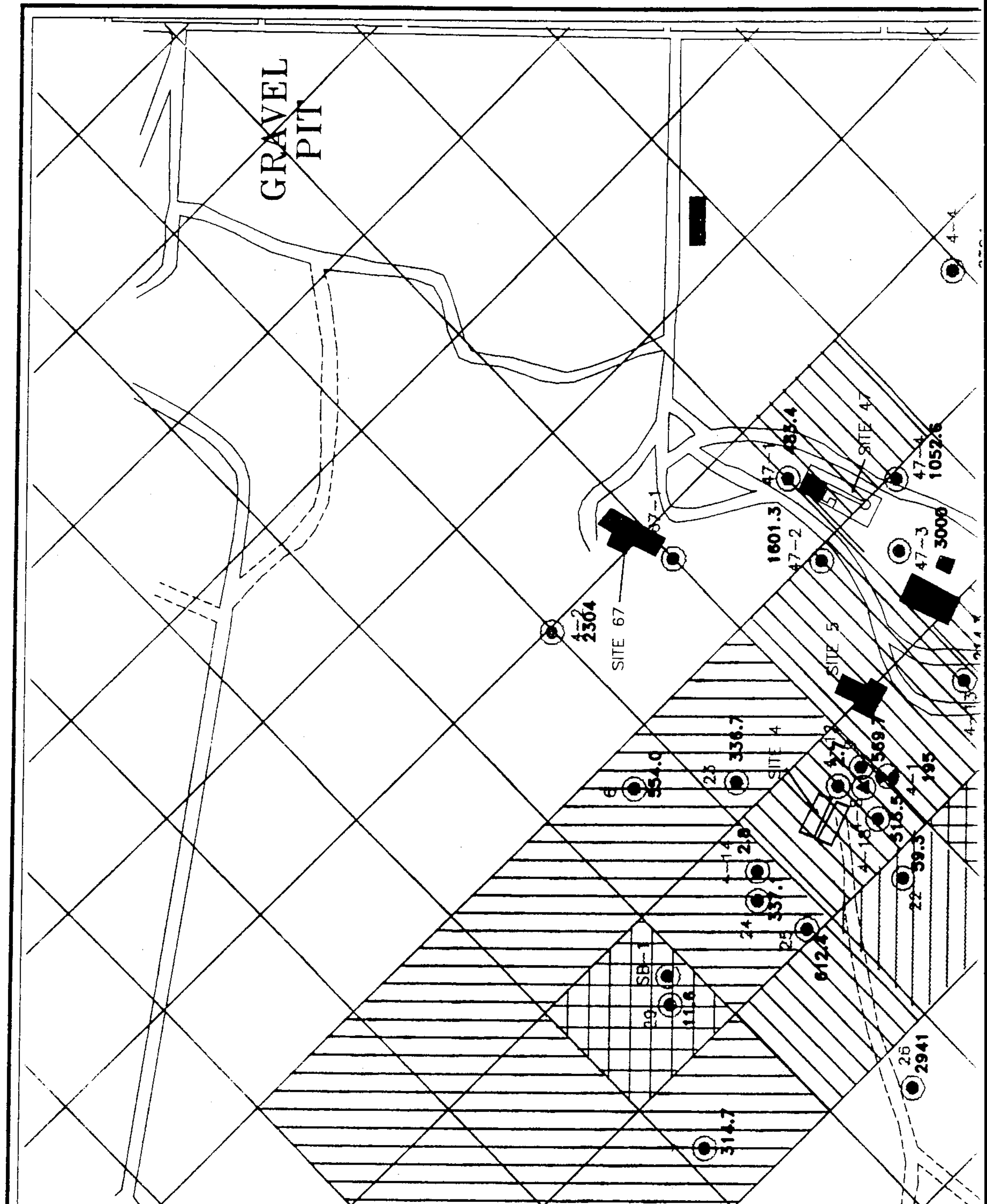

N
MODEL COLUMNS
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40
1 2 3 4 5 6 7 8 9 10 11 12
1 2 3 4 5 6 7

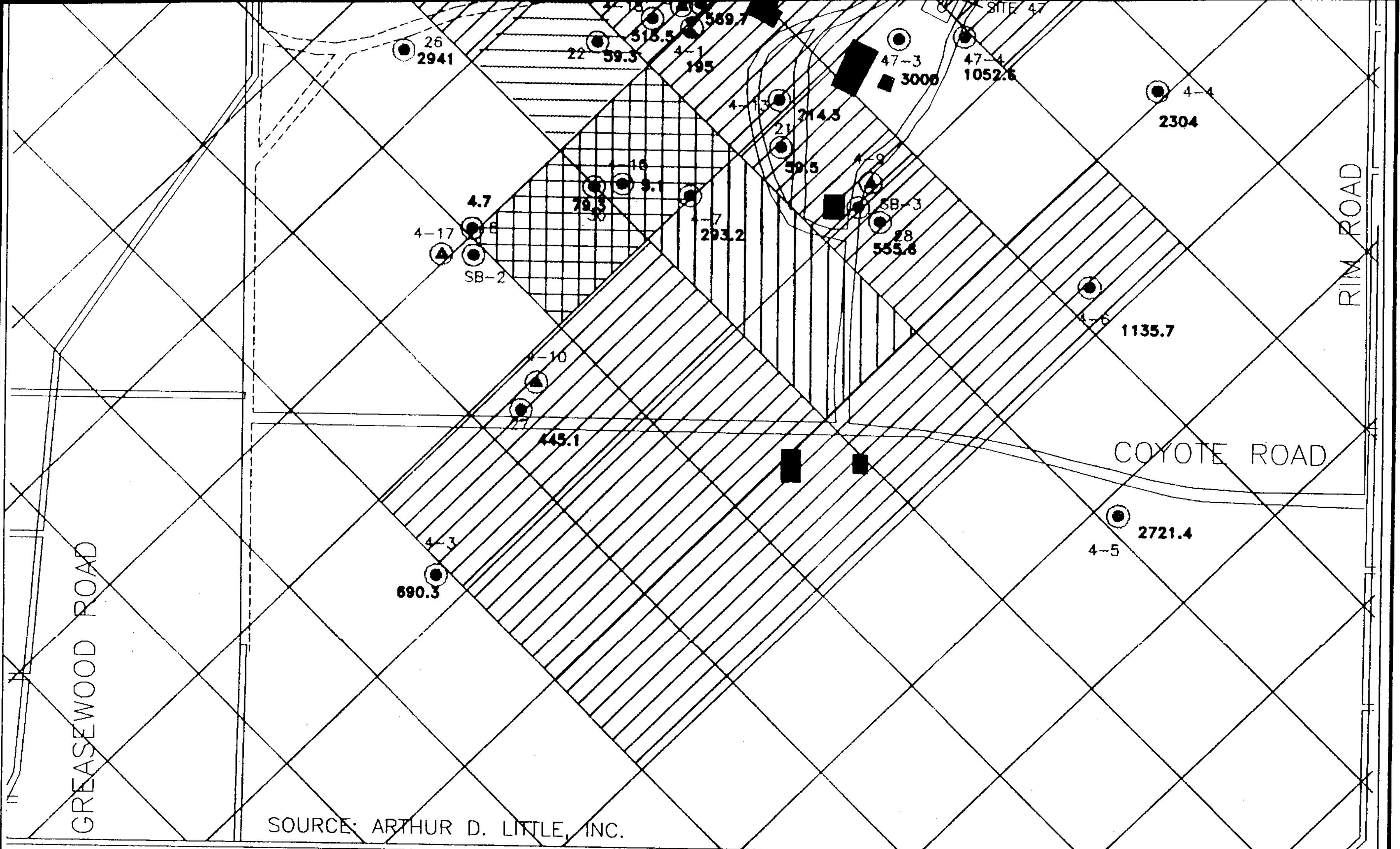

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40
80N
SCALE
0
2500

SOURCE: ARTHUR D. LITTLE, INC.

PREPARED FOR: UMATILLA			◇ Finite Difference Grid Used by MOC Model 40 Model row and column numbers X Simulated Recharge Location	TITLE: UMATILLA CONTAMINANT TRANSPORT MODEL GRID FOR CURRENT DAY HISTORICAL AND GROUND WATER EXTRACTION SCENARIOS
DATE: DEC.1993	SCALE: 1"=2500'	DWG. NO.: 67062-032		

Figure 2-1: Umatilla Contaminant Transport Model Grid


GRAVEL PIT
SITE 67
SITE 47
SITE 5
SITE 4
4-2
2304
67-1
47-1
485.4
47-4
1052.6
1601.3
47-2
47-3
3000
4-4
6
354.0
23
336.7
4-12
2.7
369.7
4-1
195
516.5
4-14
2.8
24
337.
25
612.4
22
59.5
SB-1
19
11.6
26
2941
314.7



SITE 47
26
2941
22
59.3
515.5
4-1
195
569.7
47-3
3000
47-4
1052.6
4-4
2304
4-13
214.5
21
59.5
4-9
SB-3
28
555.6
4-16
9.1
79.5
30
4-7
293.2
4.7
4-17
SB-2
4-6
1135.7
RIM ROAD
4-10
27
445.1
COYOTE ROAD
2721.4
4-5
4-3
690.3
GREASEWOOD ROAD

SOURCE: ARTHUR D. LITTLE, INC.

PREPARED FOR:
UMATILLA

DATE:	SCALE:	DWG. NO.:
DEC. 1993	1"=450 FT.	67062-030

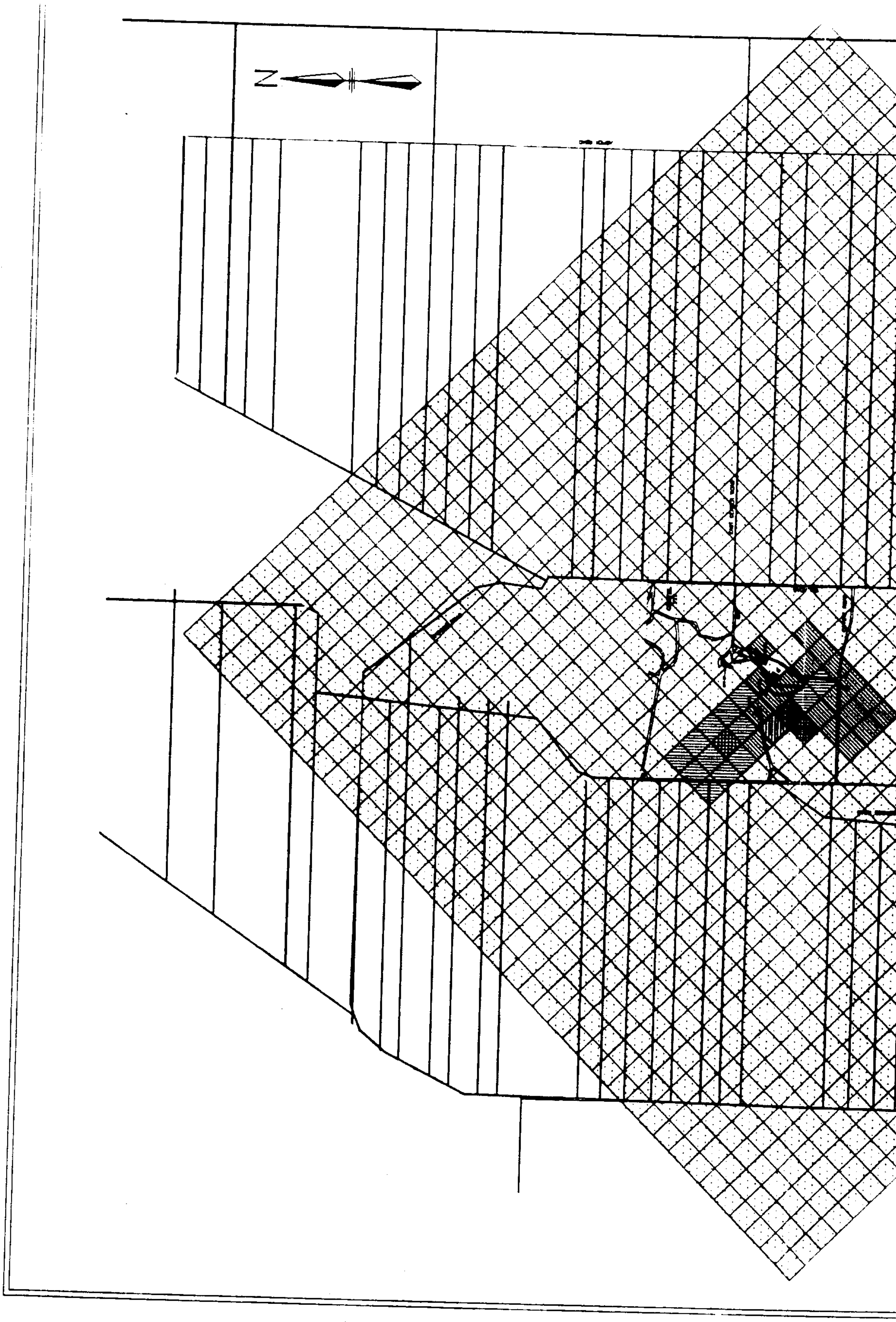
25.3 HYDRAULIC CONDUCTIVITY VALUE (FT/DAY)

◆ 29 FT/DAY
◆ 57 FT/DAY
◆ 288 FT/DAY
◆ 576 FT/DAY
◇ 2304 FT/DAY

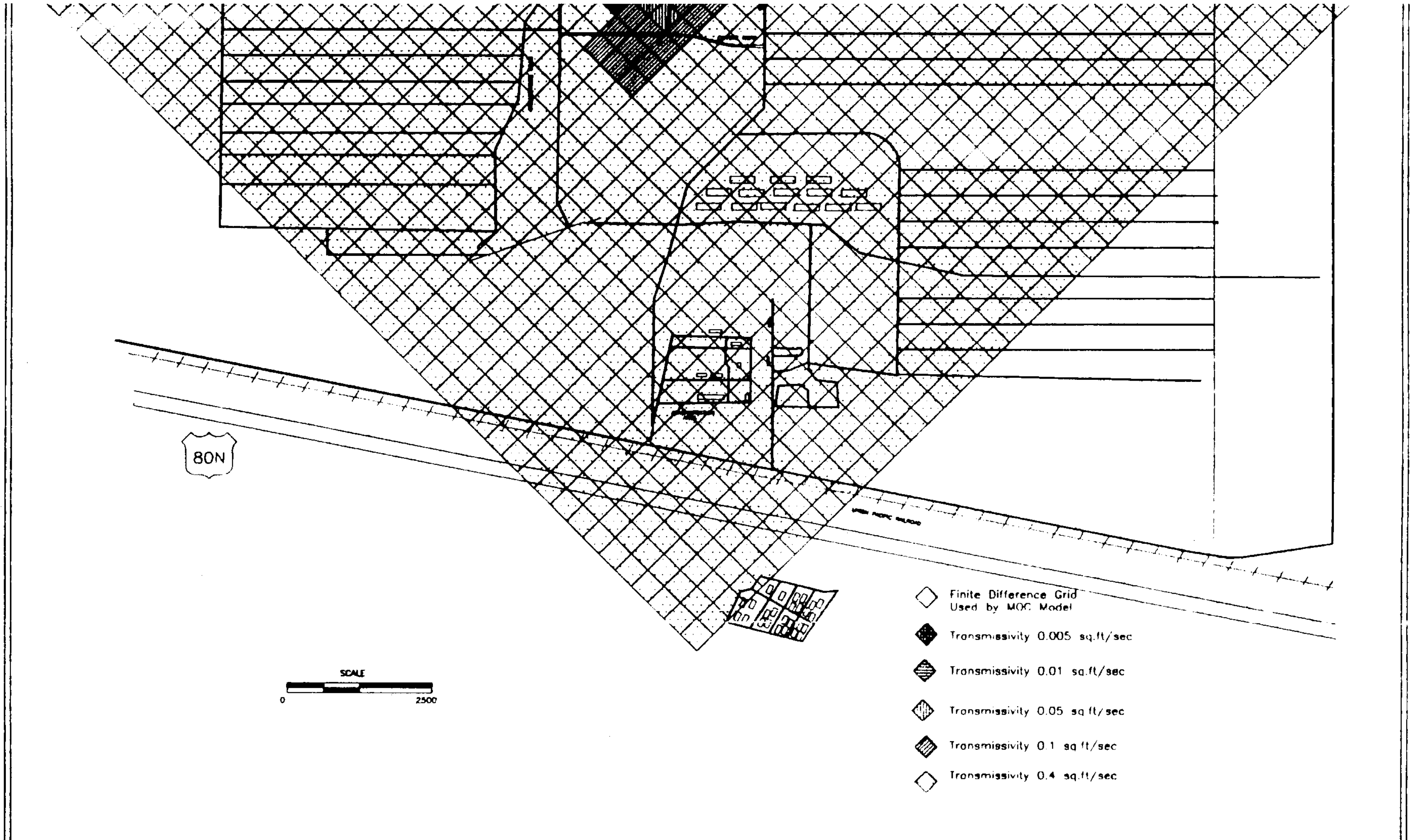
◉ 4-5 FIELD TESTED (SLUG OR PUMP TEST) HYDRAULIC CONDUCTIVITY VALUE

TITLE: **Figure 2-2:**
UMATILLA CONTAMINANT TRANSPORT MODEL HYDRAULIC CONDUCTIVITY VALUES FOR THE CURRENT DAY, HISTORICAL AND GROUND WATER EXTRACTION SCENARIOS

Figure 2-2: Umatilla Contaminant Transport Model Hydraulic Conductivity Values



1 of 2


80N
UNION PACIFIC RAILROAD
SCALE
0
2500
◇ Finite Difference Grid Used by MOC Model
◆ Transmissivity 0.005 sq.ft/sec
▤ Transmissivity 0.01 sq.ft/sec
▥ Transmissivity 0.05 sq.ft/sec
▨ Transmissivity 0.1 sq.ft/sec
◇ Transmissivity 0.4 sq.ft/sec

SOURCE: ARTHUR D. LITTLE, INC.

PREPARED FOR: UMATILLA			TITLE: UMATILLA CONTAMINATION TRANSPORT MODEL – TRANSMISSIVITY VALUES FOR THE CURRENT DAY, HISTORICAL AND GROUND WATER EXTRACTION SCENARIOS
DATE: MAR.1993	SCALE: 1" =2500'	DWG. NO.: 67062-025	

Figure 2-3: Umatilla Contamination Transport Model - Transmissivity Values for the Current Day, Historical and Ground Water Extraction Scenarios

The value of 2,300 ft/day is conservative in that it will provide for the highest transport rates in the modeled area. The reported hydraulic conductivity values (Table 2-8) were obtained from past investigation reports (Dames & Moore, 1992; Weston, 1989).

Storage Coefficient

A storage coefficient of 0.1 was chosen for the entire model based on the aquifer test results presented in the RI. Insufficient data were available to justify a variable discretization for this parameter. The storage coefficient value was based on an aquifer test of limited overall reliability (Dames & Moore, 1992a) but this was the only field value for this parameter. Since the model simulates extended time periods (i.e., 48 to 68 years) it is relatively insensitive to this parameter.

Partition Coefficients

The partition coefficients used for RDX and 2,4,6-TNT in the model were respectively 0.21 and 1.00, respectively as described by laboratory testing results presented in the RI (Dames & Moore, 1992a).

Effective Porosity

An effective porosity of 0.2 was selected based on studies by McWhorter and Sunda (1977) where they found the arithmetic average for specific yield or effective porosity of 0.2 for gravel aquifers. The effective porosity presented in the RI (0.45) was not used because there appears to be a mistake in the calculation; the effective porosity shown in the RI is probably the total porosity.

Dispersion Value

The dispersion value used by the model varied from 15 feet to 3,000 feet. The lower number for dispersion was used for the smaller grids and the larger number was used for the long-term No Action scenarios in which the contaminant traveled tens of thousands of feet. Dispersion is a scale-related parameter that is dependent on the distance traveled by the plume, and that is why a range of values was used. For comparison, Figure 2-4 is presented to show the scale dependence of dispersion. The ratio of longitudinal to transverse dispersity was set at 10:1 based on literature sources (EPRI, 1985) that indicate that longitudinal dispersity is generally higher than transverse dispersity.

Ground Water Reinfiltration

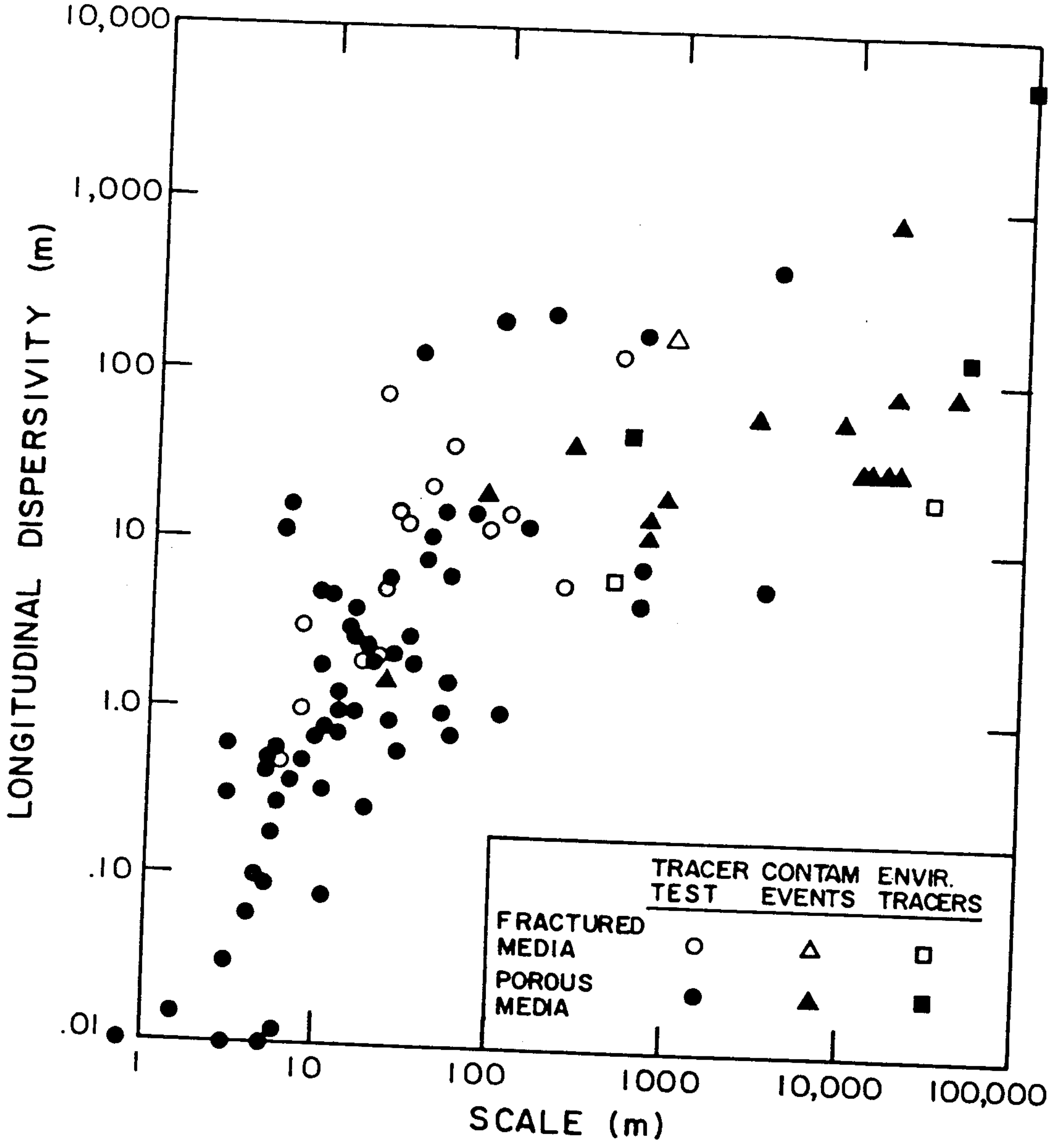
Four ground water reinfiltration scenarios were evaluated for modeling the remediation of the unconfined aquifer at Site 4, including: reinfiltration of the ground water to the washout lagoons for the length of the remediation; reinfiltration of the ground water 400 to 800 feet upgradient in an infiltration galley; reinfiltration of the of the ground water to the washout lagoons for a short period of time (to flush the contamination from the soils) followed by discharge of the water to an infiltration galley 400 to 800 feet upgradient; and reinfiltration of the ground water downgradient of the contaminant plume.

Table 2-8: Summary of Hydraulic Conductivities

Well Number	Hydraulic Conductivity (ft/day)	Reference
6	554	1
7	314.7	1
8	4.7	1
9	569.7	1
21	59.5	1
22	59.3	1
23	336.7	1
24	337.1	1
25	612.4	1
26	2941	2
27	445.1	1
28	555.6	1
29	11.6	2
30	79.3	1
4–1	195	1
4–2	2304	1
4–3	690.3	1
4–4	2304	1
4–5	2721.4	1
4–6	1135.7	1
4–7	293.2	1
4–12	2.7	1
4–13	214.3	1
4–14	2.8	1
4–15	5.1	1
4–18	515.5	1
47–1	483.4	1
47–2	1601.3	1
47–3	3000	1
47–4	1052.6	1

1. Dames & Moore, 1992a
2. Weston, 1989

Figure 2-4: Scale of Observation versus Longitudinal Dispersivity for the Saturated Zone



Source: EPRI, 1985

All four scenarios were qualitatively evaluated in the model initially to determine the effect each would have on the remediation of the ground water. The qualitative analysis was performed by using an extraction scenario with ground water reinfiltration at the infiltration galley that remediated the site to preliminary remediation goals (PRGs) in 10 years and then comparing the effect on cleanup times by varying the reinfiltration of the ground water. Based on this screening, reinfiltration of the ground water into the washout lagoons for a short period of time (to flush the contamination from the soils) followed by discharge of the water to an infiltration galley 400 to 800 feet upgradient was selected as the reinfiltration scenario to be used to evaluate the ground water extraction scenarios. The results of this screening are presented in Section 2.3.3, Ground Water Modeling Results.

Ground Water Gradient

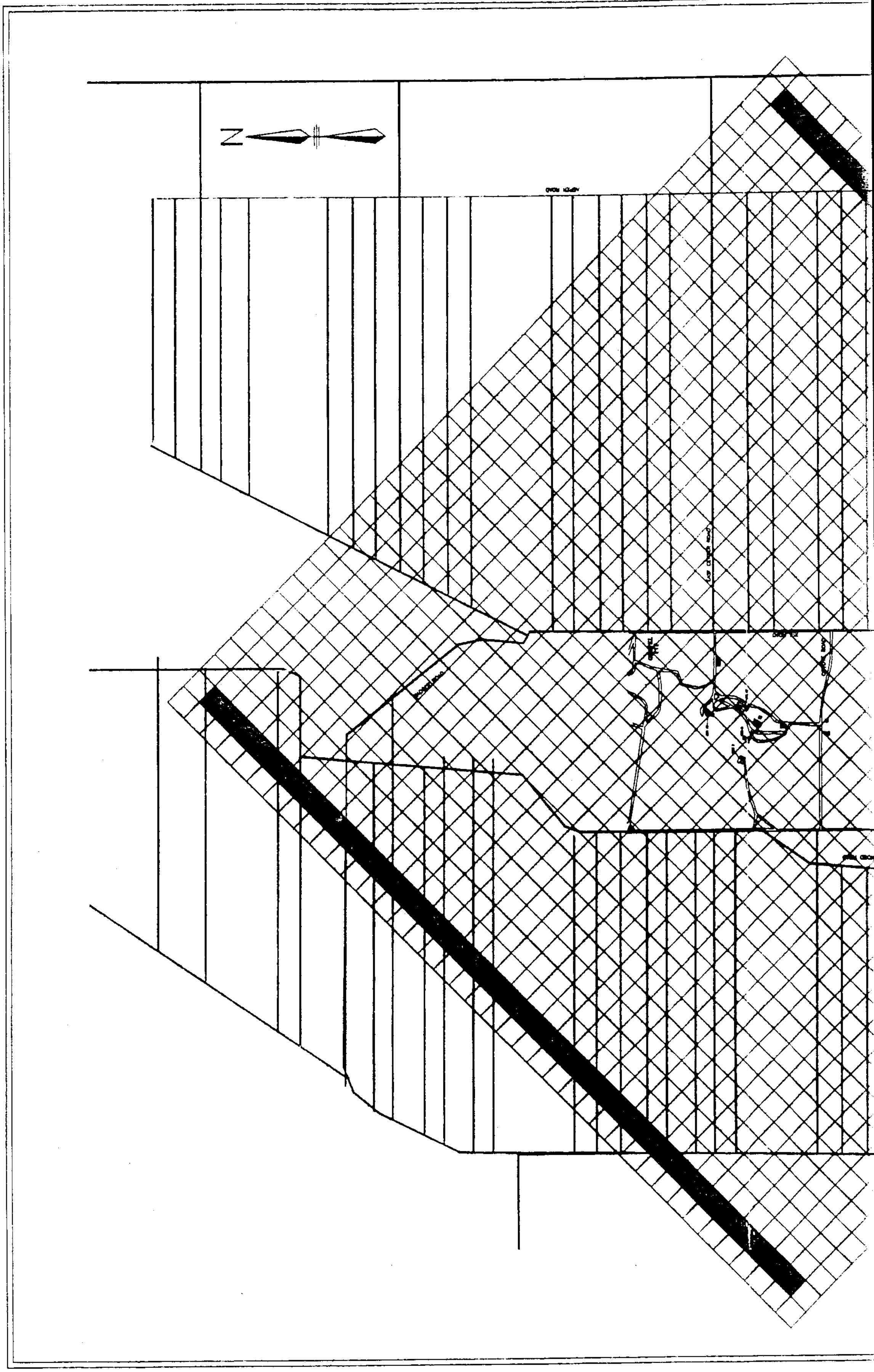
The ground water gradient is one of the least well known parameters for the site, and sufficient historical information is not available to quantitatively assess this parameter over time. Therefore, a uniform gradient throughout historical and future time of 4.7×10^{-5} ft/ft was assumed. This gradient was created by establishing fixed heads at the upper and lower model boundaries (Figure 2-5). The ground water contour interval generated by the constant head boundaries is shown in Figure 2-6. This gradient yielded a reasonable plume shape in comparison to current concentrations and areal extent. It is also based on the observed field gradients, considering that the seasonal change in ground water gradient will cause an overall average lower historical gradient than either of the seasonal values. However, as stated previously, the monitoring record is highly variable and if the average gradient were used as presented in the RI report, then the plume should be located to the northwest rather than to the southeast of the lagoons, which conflicts with the known contaminant distribution.

Contaminant Concentration Discharge to Ground Water

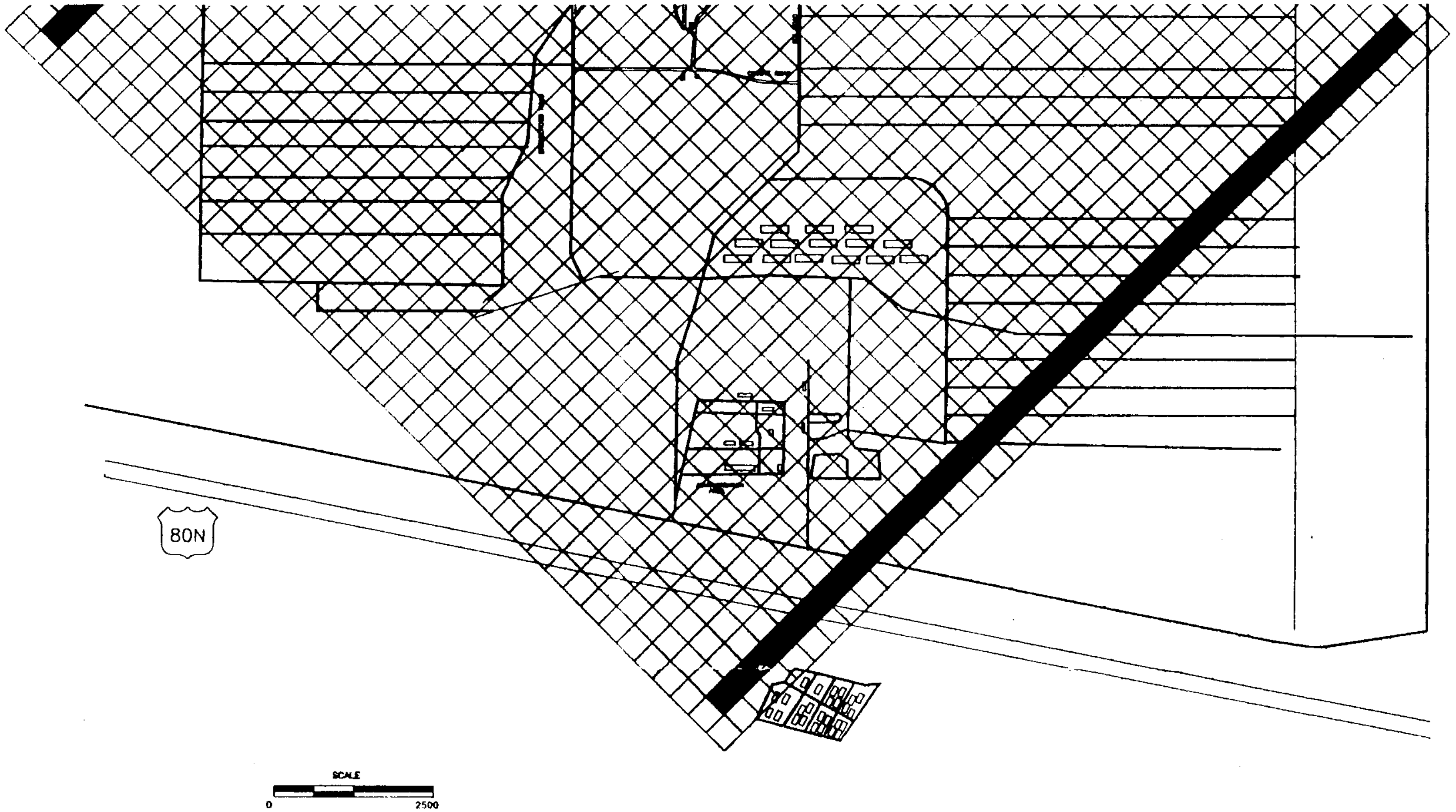
These values are below the solubility limits and are consistent with the observed concentrations in the aquifer. On average, the values of 3,000 µg/L and 4,000 µg/L are the most consistent and representative high concentrations observed in the aquifer. Therefore, these values were used for the long-term model runs. Over time, it is not expected that the concentrations in the aquifer have decreased significantly given the assumed low biodegradability of the explosives and the minimal dispersion that has apparently occurred. Therefore, the current contaminant concentrations are probably fairly reflective of the historical discharge concentrations. One sampling event found an RDX concentration of 6,816 mg/L in Well 28; however, this concentration was not used because concentrations this high were never detected in subsequent sampling events and is not consistent with trends from other wells.

Historic Discharge to the Lagoons

The historic lagoon discharge (injection rate) was modeled as a discharge well that received 8.5 million gallons/year of wastewater for 10 years. This model condition was


N
ASPEN ROAD

1 of 2



SOURCE: ARTHUR D. LITTLE, INC.

PREPARED FOR:
UMATILLA

DATE:
MAR.1993

SCALE:
1"=2500'

DWG. NO.:
67062-036

◇ Finite Difference Grid Used by MOC Model

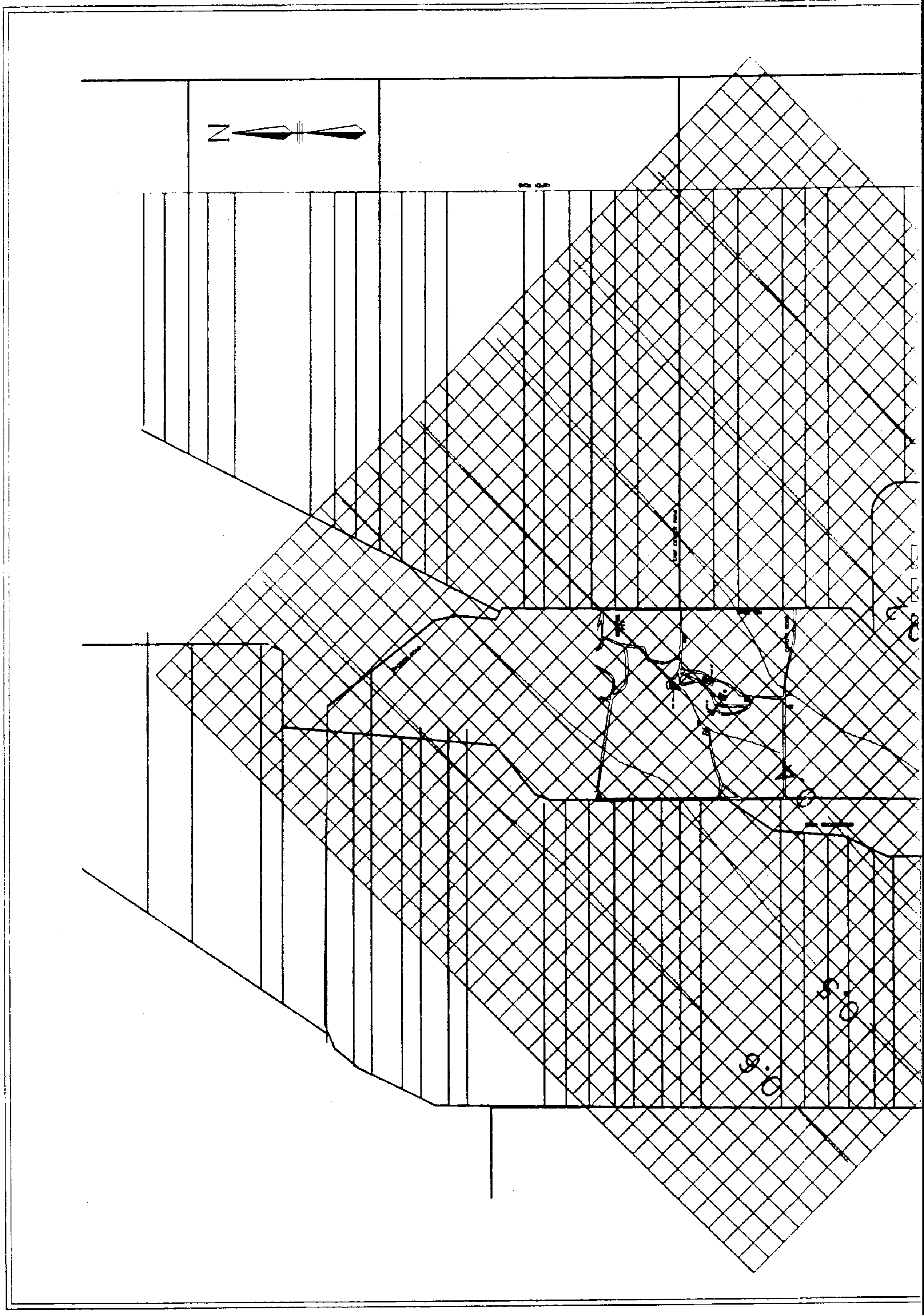
■ CONSTANT HEAD BOUNDARY CELLS

TITLE: **Figure 2-5:**

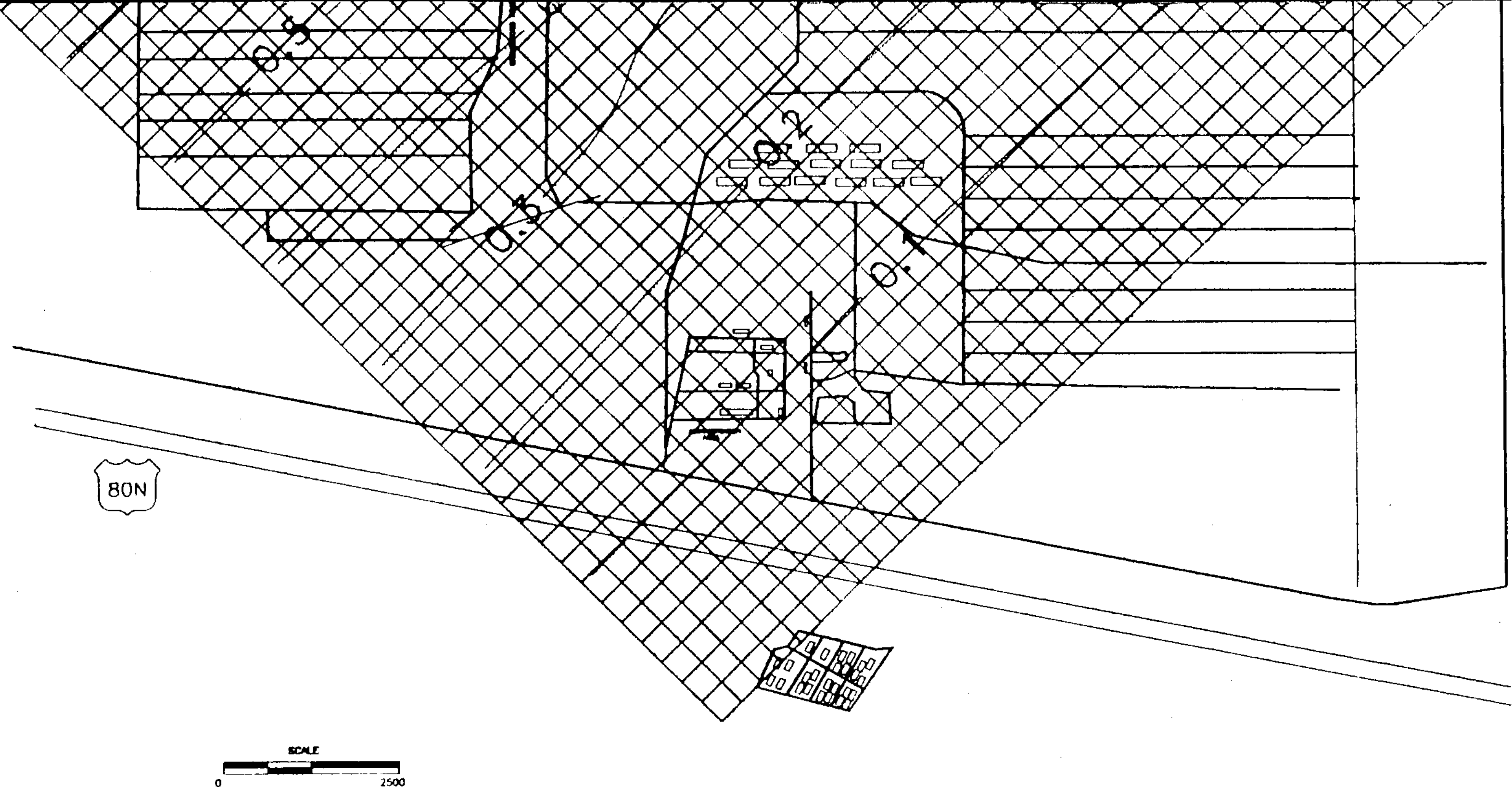
CONTAMINANT TRANSPORT MODEL
BOUNDARY CONDITIONS

Figure 2-5: Contaminant Transport Model Boundary Conditions

272



1 of 2



SOURCE: ARTHUR D. LITTLE, INC.

PREPARED FOR:
UMATILLA

DATE:
MAR.1993

SCALE:
1" =2500'

DWG. NO.:
67062–026

◇ Finite Difference Grid
Used by MOC Model

⌊0.2⌝ Simulated Water Table Ccontour In Feet

TITLE:

CONTAMINANT TRANSPORT MODELLED
GROUND WATER CONTOURS

Figure 2-6: Contaminant Transport Model CAD Ground Water Contours

based on the historical record, which showed that from the period of about 1955 to 1965, approximately 85 million gallons of wastewater were disposed of in the Explosive Washout Lagoons (16 gpm).The contaminant concentration of RDX and 2,4,6-TNT discharged to the aquifer at the lagoons was assumed respectively to be 3,000 µg/L and 4,000 µg/L.

Current Contaminant Conditions

To achieve the current contaminant conditions, the long-term transport simulations were modeled as transient over the period of 10 years when the contaminated wastewater was injected into the aquifer. The period of wastewater discharge was followed by no more contaminant addition and 28 years of contaminant migration (until 1991). The current simulated contaminant plume is shown in Figures 2-7 and 2-8 for RDX and 2,4,6-TNT, respectively. The field monitoring well data have not definitively defined the extent of the contaminant plume in all directions (i.e., southeast and west). The observed plume boundaries do, for the most part, correspond with the simulated plume area. Also, the simulated concentrations agree reasonably well with the observed concentrations. Since the simulated plume generated from the original operations (1955 to 1965) corresponds reasonably well to the actual, documented plume, the reasonableness of the assumed concentrations and site properties is verified. However, to the north of the site the simulated plume extends beyond the observed plume area. This discrepancy is due to the mathematical simulation of dispersion included in the model, which tends to allow contaminants to migrate upgradient more than observed in nature. This problem cannot be corrected in the code without changing the mathematical formulation, rather, the simulated upgradient concentrations should be reviewed with caution; however, based on the overall agreement, the model was assumed to be calibrated. As can be seen in Figure 2-7, the contaminant plume extends about 3,700 feet from the disposal lagoons and is at most about 2,500 feet wide. The correlation of the simulated contours with the actual data indicates that the parameters that have been used in the model are reasonably representative of the site.

The model data set for the first 10 years of contaminant injection and 28 years of contaminant migration is presented in Appendix A. In most cases, the other data sets would be similar except for the changes noted in this section.

2.3.3 Ground Water Modeling Results

As stated at the beginning of this section, the objective of this model was to develop engineering estimates to allow remedial alternatives to be evaluated. This model is not intended to take the place of modeling that will be needed to optimize the location of the reinfiltration galley or the location and number of the extraction wells. Three ground water modeling efforts were conducted to meet the stated objective. These included:

- Ground Water Reinfiltration
- Ground Water Extraction

- Natural Attenuation

To facilitate the review of the results, each modeling effort is separately presented below; however, it should be realized that the ground water reinfiltration and ground water extraction efforts were iterative.

2.3.3.1 Ground Water Reinfiltration. Four ground water reinfiltration scenarios were evaluated for modeling the remediation of the unconfined aquifer at Site 4, including: reinfiltration of the ground water to the washout lagoons for the length of the remediation; reinfiltration of the ground water 400 to 800 feet upgradient in an infiltration galley; reinfiltration of the of the ground water to the washout lagoons for a short period of time (to flush the contamination from the soils) followed by discharge of the water to an infiltration galley 400 to 800 feet up gradient; and reinfiltration of the ground water downgradient of the contaminant plume.

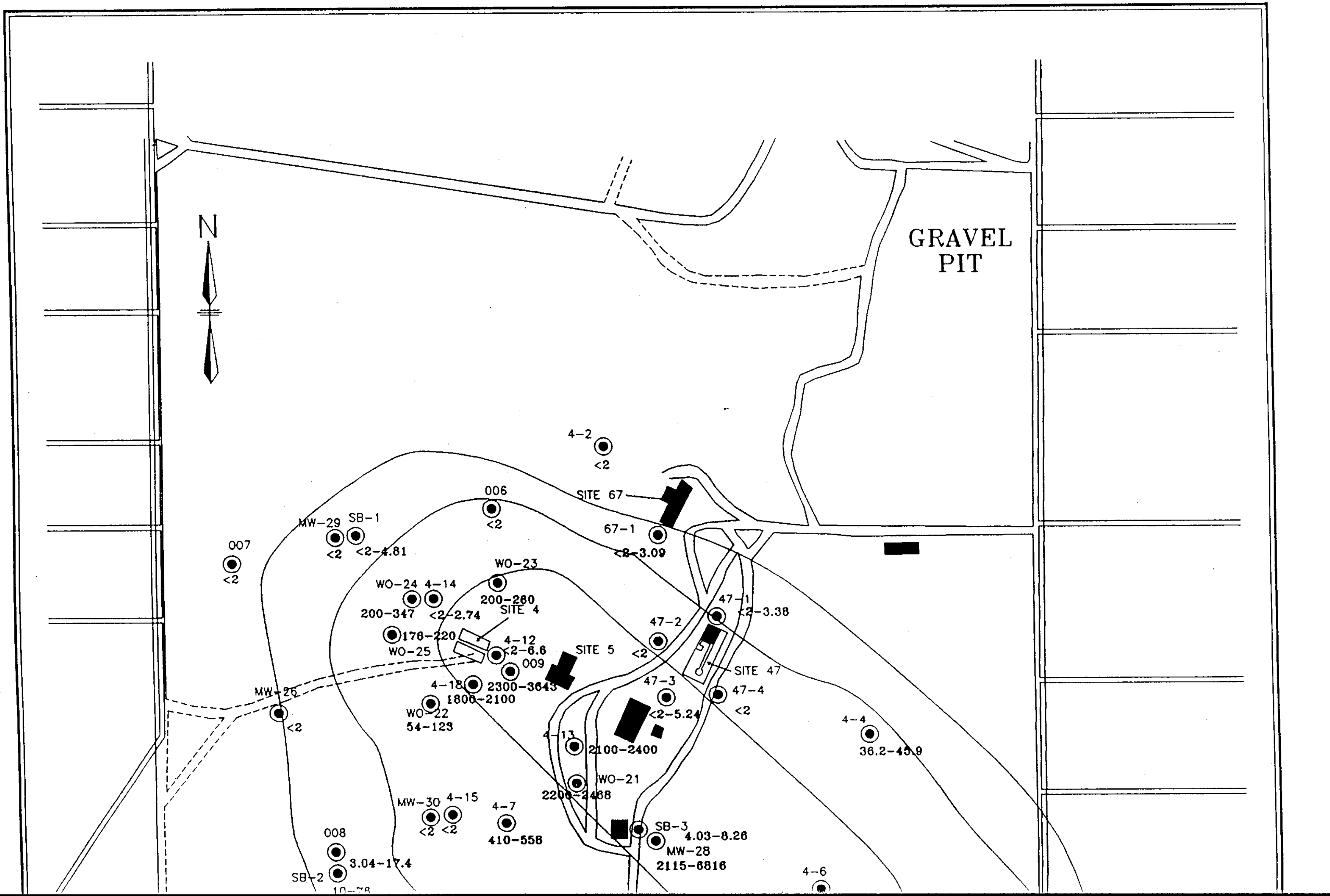
All four scenarios were qualitatively evaluated in the model initially to determine the effect each would have on the remediation of the ground water. The qualitative analysis was performed using three extraction wells at a flow rate of 333gpm with ground water reinfiltration at the infiltration galley that remediated the site to PRGs in 10 years and then comparing the effect on cleanup times by varying the reinfiltration of the ground water. Based on this screening, reinfiltration of the ground water into the washout lagoons for a short period of time (to flush the contamination from the soils) followed by discharge of the water to an infiltration galley 400 to 800 feet upgradient was selected as the reinfiltration scenario to be used to evaluate the ground water extraction scenarios. The results of this screening are presented below by reinfiltration scenario.

Reinfiltration Upgradient - Baseline

The baseline case upon which each of the other reinfiltration scenarios was evaluated was the reinfiltration of the treated ground water upgradient of the washout lagoons. In this scenario, the ground water extracted from the aquifer was modeled as being reinjected at an equal discharge rate back into the aquifer in a region 400 to 800 feet upgradient of the washout lagoons (i.e., two model grid squares upgradient [Figure 2-1]). The scenario was evaluated using a pumping rate of 333 gpm from three extraction wells at nodes (20,18), (20,20), and (20,22) from Figure 2-1. The results of this scenario showed that the aquifer could be remediated to PRGs in 10 years.

Reinfiltration Downgradient

In this scenario, the ground water extracted from the aquifer was modeled as being reinjected at an equal discharge rate back into the aquifer downgradient of the contaminant plume in a manner that would not effect the remediation of the ground water. The scenario used the same extraction rates and extraction well locations as the baseline scenario as a starting point for the evaluation. The results of the modeling showed that the extraction flow rate had to be increased to 430 gpm to remediate the aquifer to PRGs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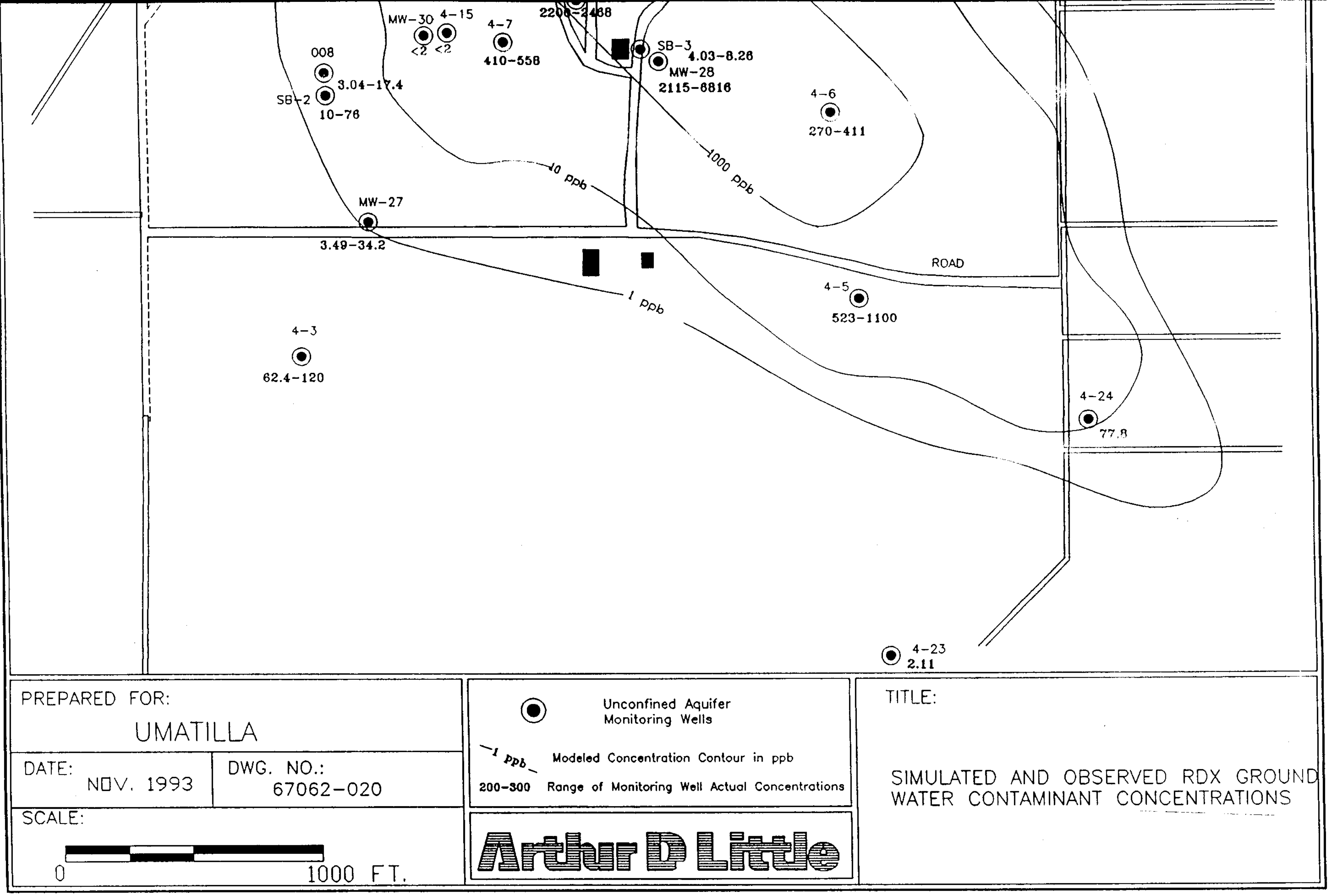
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523-1100
4-3
62.4-120
4-24
77.8
4-23
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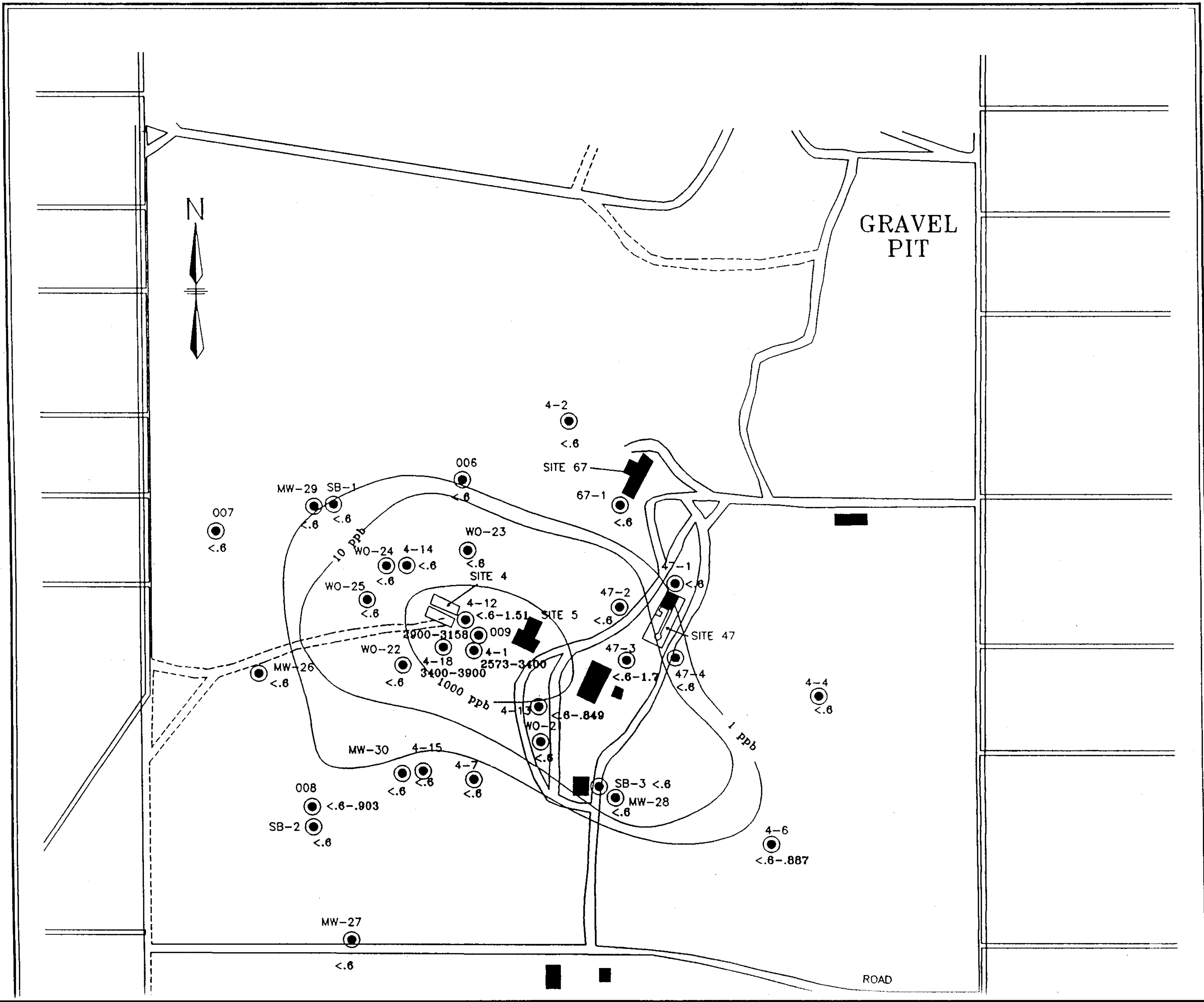
PREPARED FOR:
UMATILLA
DATE:
NOV. 1993
DWG. NO.:
67062-020
SCALE:
0
1000 FT.
Unconfined Aquifer Monitoring Wells
1 ppb
Modeled Concentration Contour in ppb
200-300
Range of Monitoring Well Actual Concentrations
Arthur D Little
TITLE:
SIMULATED AND OBSERVED RDX GROUND WATER CONTAMINANT CONCENTRATIONS

Figure 2-7: Simulated and Observed RDX Ground Water Contaminant Concentrations (January 1991)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67-1
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SB-1
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WO-25
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4-12
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SITE 5
2900-3158
009
4-1
2573-3400
WO-22
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4-18
3400-3900
1000 ppb
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47-1
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47-2
<.6
SITE 47
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4-7
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008
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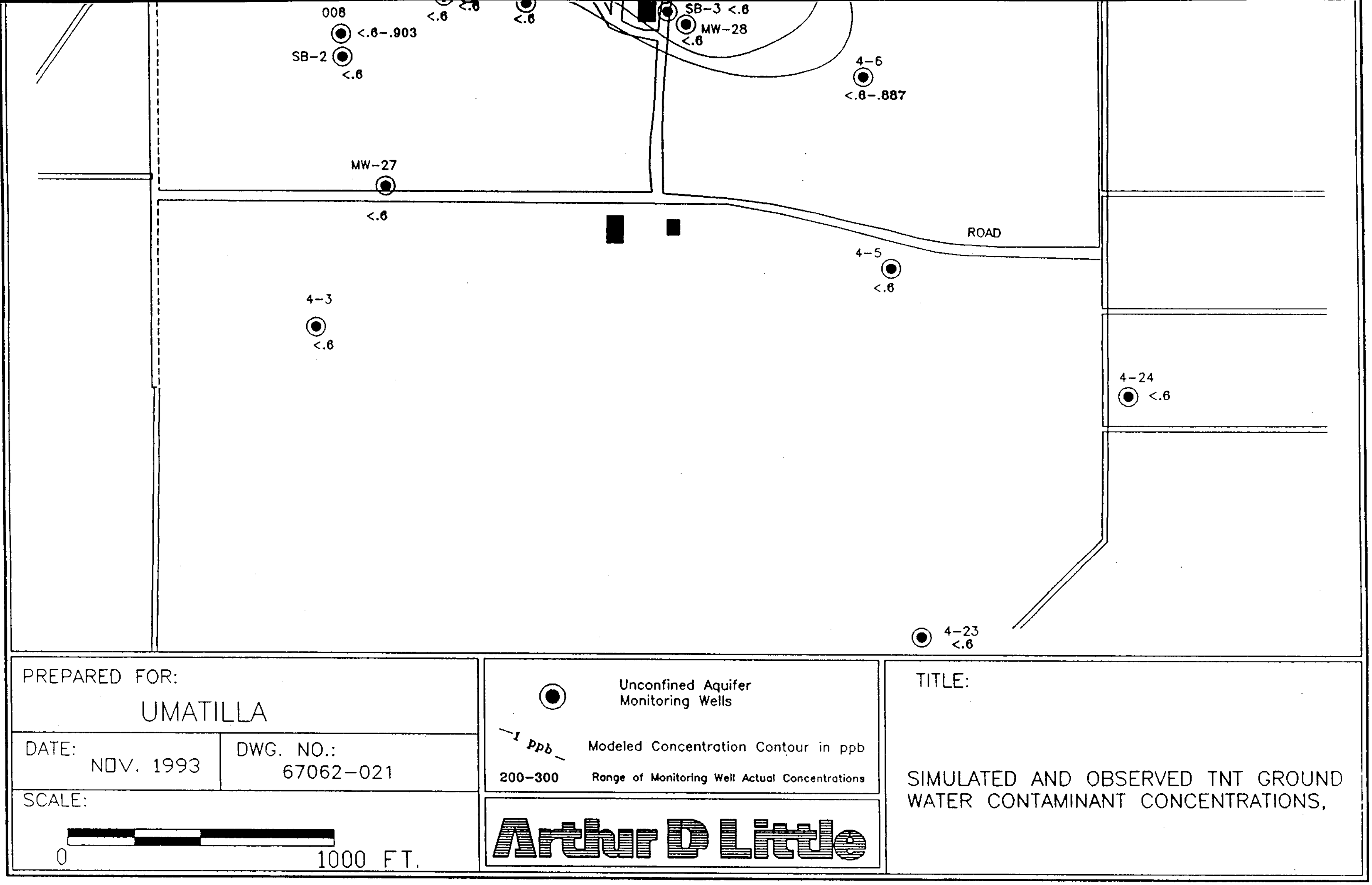
ROAD

1 of 3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ROAD
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PREPARED FOR:
UMATILLA
DATE:
NOV. 1993
DWG. NO.:
67062-021
SCALE:
0
1000 FT.
Unconfined Aquifer Monitoring Wells
1 ppb
Modeled Concentration Contour in ppb
200-300
Range of Monitoring Well Actual Concentrations
Arthur D Little
TITLE:
SIMULATED AND OBSERVED TNT GROUND WATER CONTAMINANT CONCENTRATIONS,

Figure 2-8: Simulated and Observed 2,4,6-TNT Ground Water Contaminant Concentrations (January 1991)

within 10 years. The increase in extraction rate represented a 23 percent increase in extraction rate over the baseline scenario.

Reinjection to the Washout Lagoons

In this scenario, the ground water extracted from the aquifer was modeled as being reinjected at an equal discharge rate back into the aquifer at the washout lagoons. The scenario used the same extraction rates and extraction well locations as the baseline scenario. In this model run where the treated ground water was discharged back into the washout lagoons for the life of the remediation (10 years), the reinfiltration resulted in an adverse spreading of the contaminants caused by the ground water mounding. In particular, the model runs indicated that by discharging into the washout lagoons, a radial flow pattern was established at the lagoons that caused contaminants below the lagoons to spread out into currently uncontaminated areas to the northeast and southwest. Instead of forcing the contaminants towards the extraction wells, the discharge tended to spread the contaminants by sending them radially towards lower permeability sediments. Even at pumping rates twice as high as the baseline scenario, the extraction wells were not able to remediate the aquifer to PRGs within the 10 year time frame.

Reinfiltration to the Washout Lagoons followed by Reinfiltration Upgradient

In this scenario, the ground water extracted from the aquifer was modeled as being reinjected at a rate of 200 gpm into the washout lagoons with the remaining 133 gpm being reinjected upgradient. After one year, the ground water being reinjected at the washout lagoons was redirected to the upgradient reinjection location. The scenario used the same extraction rates and extraction well locations as the baseline scenario. The reinfiltration to the lagoons caused a discharge of 0.5 mg/L RDX and 0.3 mg/L TNT to the ground water from the contaminated soils (Appendix A). The modeling results indicated that a short-term reinjection into the washout lagoons would remediate the aquifer to PRGs within 10 years without increasing the extraction rates. Unlike reinfiltration to the washout lagoons for the entire remediation, reinfiltration to the lagoons for a short period did not cause the contaminants to spread out and contaminate previously uncontaminated regions of the aquifer. Because this scenario provides similar remediation to the baseline case and it also provides for removal of the remaining explosive contamination in the soils, it was selected as the reinfiltration alternative for the detailed analysis.

2.3.3.2 Ground Water Extraction. To simulate remedial extraction systems a variety of well patterns and well pumping rates were modeled. Given the wide variety of potential well locations and pumping rates, a few select options were implemented that were consistent with those commonly used to remediate contaminated sites (Satkin and Bedient, 1988). Typically, there is a trade off between the number of wells installed, the pumping rate, and the cleanup time that results. Whereas a larger number of wells may clean up an area faster and save on operation and maintenance cost, it results in a higher capital cost. Also, a large pumping rate may decrease the cleanup time but at the risk of having to treat more uncontaminated water than may be accomplished by a lower flow rate.

The well patterns and flow rates modeled and their corresponding cleanup times are listed in Table 2-9. All modeling runs presented in Table 2-9 were performed with the ground water reinjected 400 to 800 feet upgradient of the washout lagoons (see Section 2.3.3.1, Ground Water Reinfiltration). The modeling indicated that the upper bound for well pumping rate is approximately 0.5 ft^3/sec (225 gpm); at rates not much higher than this, the well would be expected to dewater the area. For example, at a rate of 0.5 ft^3/sec (225 gpm) a well will experience about 6.5 feet of drawdown given the MOC drawdown results corrected for a point location by the formulations of Peaceman (1983).

The upper bound for well pumping limits the remedial program to a multi-well remediation, because one well cannot clean up the site at this pumping rate. The remediation strategy is also constrained by the spread of contamination over a large area due to the variation in partition coefficient among the explosives. Therefore, it becomes necessary to install at least three wells to clean up the site. A greater number of wells tended to cause large stagnation areas to form that interfered with the cleanup, whereas fewer wells were not able to efficiently capture the contaminants. For modeling purposes, it was assumed that remedial well pumping began in January 1993.

Whereas the remedial well data set is not exhaustive, it does give a range of anticipated cleanup times for a selection of well configurations and pumping rates. The results indicate that to meet a cleanup level of 10^{-4} and a hazard index of 1 (RDX = 77 µg/L, 2,4,6-TNT = 18 µg/L), it will take significantly less time and/or a lower flow rate by about a factor of two than cleanup to the PRGs (RDX = 2.1 µg/L, 2,4,6-TNT = 2.8 µg/L).

Based on the results of the modeling, four extraction scenarios were selected for use in the detailed analysis (highlighted in Table 2-9 and presented in Table 2-10). These scenarios are representative of how the actual extraction system may operate, but they are not optimized and additional modeling will be needed during the remedial design to determine the actual number of extraction wells, their location, and pumping rates.

In the simulated extraction scenarios, the contaminant capture zone extends beyond the known contaminated areas, therefore, the extraction well scenarios are conservative. The capture zone areas were estimated by observing the ground water gradient map. Areas where the gradient vector point towards an extraction well were assumed to be captured, while those moving away from the wells were assumed to be outside the capture zone. The capture zone maps for the four selected extraction scenarios are presented in Section 4.0, Detailed Analysis. In addition to the capture zones, intermediate and final contours for both RDX and 2,4,6-TNT were developed and are presented in Section 4.0.

Table 2-9: Scenarios Tested for Well Placement and Pumping Rate Optimization

Scenario	Well Locations* (grid cells) (row, column)	Pumping Rates (ft3/sec)	Qualitative Results
RDX, 10 year, 10 -4 cleanup	(20,18)(20,20)(20,22)	(0.15)(0.05)(0.22)	Cleanup level not achieved
	(20,18)(20,20)(20,22)	(0.25)(0.07)(0.10)	Stagnation zone at (20,21)
	(20,18)(20,20)(20,22)	(0.25)(0.1)(0.07)	Cleanup level not achieved
	(20,18)(20,20)(20,22)	(0.23)(0.12)(0.07)	OK for RDX, not for TNT
	(20,18)(20,20)(20,22)	(0.46)(0.24)(0.14)	Cleanup level achieved
	(20,18)(20,20)(20,22)	(0.37)(0.1)(0.07)	OK for RDX, not for TNT
	(20,18)(20,20)(20,22)	(0.37)(0.06)(0.03)	Cleanup level achieved
	(20,18)(20,20)(20,22)	(0.37)(0.04)(0.01)	Cleanup level not achieved
	(20,18)(20,20)(20,22)	(0.37)(0.05)(0.01)	Cleanup level not achieved
	**(20,18)(20,20)(20,22)	(0.37)(0.06)(0.01)	Cleanup level achieved RDX & TNT
TNT, 10 year, 10 -4 cleanup	(20,18)(20,20)(20,22)	(0.2)(0.1)(0.12)	Cleanup level not achieved
	(20,18)(20,20)(20,22)	(0.23)(0.12)(0.07)	Cleanup level not achieved
	(20,18)(20,20)(20,22)	(0.25)(0.15)(0.07)	Cleanup level not achieved
	(20,18)(20,20)(20,22)	(0.30)(0.13)(0.07)	Cleanup level not achieved
	(20,18)(20,20)(20,22)	(0.37)(0.10)(0.07)	Cleanup level not achieved
	**(20,18)(20,20)(20,22)	(0.37)(0.06)(0.01)	Cleanup level achieved
RDX, 30 year, 10 -6 cleanup	(20,18)(20,21)(20,24)	(0.3)(0.06)(0.02)	Cleanup level achieved
	(20,18)(20,21)(20,24)	(0.2)(0.06)(0.02)	Cleanup level not achieved
	(20,18)(20,21)(20,24)	(0.18)(0.06)(0.04)	Cleanup level achieved
	(20,18)(20,19)(20,20) (20,21)(20,22)	(all 0.15)	Cleanup level not achieved
	(20,18)(20,19)(20,21) (20,22)	(0.2)(0.2)(0.2) (0.15)	Cleanup level not achieved
	(20,18)(20,22)	(0.4)(0.35)	Cleanup level not achieved Stagnation zone at (20,21)
	(20,20)	(0.5)	Cleanup level not achieved
	**(20,18)(20,21)(20,24)	(0.2)(0.06)(0.04)	Cleanup level achieved
TNT, 30 year, 10 -6 cleanup	(20,18)(20,21)(20,24)	(0.3)(0.06)(0.01)	Cleanup level achieved
	(20,18)(20,21)(20,24)	(0.2)(0.06)(0.02)	Cleanup level achieved
	(20,18)(20,21)(20,24)	(0.18)(0.06)(0.04)	Cleanup level not achieved
	**(20,18)(20,21)(20,24)	(0.2)(0.06)(0.04)	Cleanup level achieved
RDX, 10 year, 10 -6 cleanup	(20,18)(20,20)(20,22)	(0.47)(0.16)(0.04)	Cleanup level not achieved
	(20,18)(20,20)(20,22)	(0.47)(0.16)(0.06)	Cleanup level achieved
	(20,18)(20,20)(20,22)	(0.4)(0.16)(0.06)	Cleanup level not achieved
	(20,18)(20,20)(20,22)	(0.38)(0.18)(0.06)	Cleanup level achieved
	(20,18)(20,20)(20,22)	(0.38)(0.16)(0.08)	Cleanup level achieved
	**(20,18)(20,20)(20,22)	(0.5)(0.16)(0.08)	Cleanup level achieved
TNT, 10 year, 10 -6 cleanup	(20,18)(20,20)(20,22)	(0.38)(0.16)(0.08)	Cleanup level not achieved
	(20,18)(20,20)(20,22)	(0.4)(0.16)(0.08)	Cleanup level not achieved
	(20,18)(20,20)(20,22)	(0.42)(0.16)(0.08)	Cleanup level not achieved
	(20,18)(20,20)(20,22)	(0.48)(0.16)(0.08)	Cleanup level not achieved
	**(20,18)(20,20)(20,22)	(0.5)(0.16)(0.08)	Cleanup level achieved
RDX, 30 year, 10 -4 cleanup	(20,18)(20,21)(20,24)	(0.1)(0.03)(0.02)	Cleanup level not achieved
	(20,18)(20,24)	(0.1)(0.01)	Cleanup level not achieved
	**(20,18)(20,21)(20,24)	(0.12)(0.03)(0.02)	Cleanup level achieved
TNT, 30 year, 10 -4 cleanup	**(20,18)(20,21)(20,24)	(0.12)(0.03)(0.02)	Cleanup level achieved
	(20,18)(20,21)(20,24)	(0.1)(0.03)(0.02)	Cleanup level achieved
	(20,18)(20,21)(20,24)	(0.11)(0.03)(0.02)	Cleanup level not achieved

* See Figure 2-1 for grid locations

** Scenario selected for use in detailed analysis

Source: Arthur D. Little, Inc.

Table 2-10: Results of Ground Water Model for UMDA

Remedial Scenario	Number of Wells	Total Pumping Rate (gpm)	Years to Meet Cleanup Levels
No Action			
PRGs (a)	0	0	5000 (c)
Risk Level of 1.00E-4 (b)	0	0	330 (c) (d)
Pump and Treat 1			
PRGs (a)	3	333	10
Risk Level of 1.00E-4 (b)	3	200	10
Pump and Treat 2			
PRGs (a)	3	138	30
Risk Level of 1.00E-4 (b)	3	77	30

Notes:

(a) The preliminary remedial goal for RDX is 2.1 µg/L and for 2,4,6-TNT is 2.8 µg/L

(b) The risk level of 1.00E-4 is at a concentration of 77 µg/L for RDX and 18 µg/L for 2,4,6-TNT

(c) The RDX plume will reach the UMDA boundary within approximately 70 years

(d) 2,4,6-TNT will meet the goal in approximately 250 years

Source: Arthur D. Little, Inc.

2.3.3.3 Natural Attenuation. The long range "no action" scenarios were evaluated by extending the grid dimensions and grid block sizes to allow for greater contaminant travel distances. As a cautionary note, changing these dimensions changes the interpretation of contaminant concentration plots because the block represents a larger aquifer volume and consequential dilution can occur over certain intervals.

The results of the long-term contaminant transport modeling are shown in Table 2-10. They indicate that if no remedial actions are taken, then it will take, respectively, approximately 5,000 and 330 years for the RDX plume to decline below the preliminary remedial goals and 10^{-4} risk-based cleanup criteria. Over this time period, the plume is expected to travel about 300,000 and 40,000 feet, respectively, from the disposal lagoons before natural attenuation is achieved. The results for natural attenuation of the 2,4,6-TNT plume were similar to the RDX plume. The 2,4,6-TNT plume will take approximately 5,000 and 250 years, respectively, to reach the preliminary remedial goals and 10^{-4} risk-based cleanup criteria. Over this time period, the plume will travel about 100,000 and 12,000 feet, respectively, from the Explosive Washout Lagoons. The model also indicates that under the no action scenario, the RDX plume will reach the UMDA boundary within about 70 years.

2.3.4 Model Restrictions

The contaminant transport model of the site was developed to estimate the time required to meet remedial objectives in order to develop approximate remedial cost estimates based on the conditions that exist now. The modeling is not intended to serve as an in-depth, historical, all inclusive model for the ground water system, rather, it relies on average values of geohydrologic parameters for the site and on the empirical field data to develop the model.

The model developed was for the uppermost unconfined aquifer only and is two-dimensional; therefore, it does not take into account unsaturated flow and vertical movement between layers or within the unconfined aquifer. These effects would be expected to be small. No areal recharge was simulated and the area outside the study area was considered homogeneous due to the lack of data. Artificial recharge was not simulated because it occurs outside the modeled area except in the "no action" scenarios and insufficient data are available to characterize its impact. The upgradient and downgradient model boundaries are simulated as constant head, therefore, they take into account a ready supply of artificial recharge. For the long-term contaminant transport scenarios, an assumption was made that the contaminants would travel within the uppermost aquifer along the same direction as they have previously and at the same gradient.

2.3.5 Sensitivity Analysis

A sensitivity analysis was conducted to evaluate how changes in input parameters impact the model results. The purpose of the analysis was to determine which parameters have the greatest effect on the modeled results and to determine to what extent model accuracy, and therefore pumping design accuracy, is dependent upon variation in input parameters. However, it should be noted that the purpose of this model is to develop engineering estimates that can be used in the development and evaluation of alternatives. Additional modeling will be required during the remedial design to optimize the placement and extraction rate of the wells.

The sensitivity analysis was conducted in two steps. During both steps a base case selected from the extraction model results was used to evaluate the changes. The first step identified which parameters have the greatest affect on the results of the simulated plume, and the second step evaluated, for the parameter with the greatest effect, the influence on the pumping rate and remediation time.

- During the first step, the base case of the model was run while individually varying five parameters: hydraulic conductivity (transmissivity), effective porosity, gradient, dispersivity, and contaminant retardation. The base case used for this analysis was for RDX and did not include any pumping wells. The effects of the parameters on the model were measured through relative changes in plume length and area. Other parameters were not selected because they were not believed to cause a major change in the model results or there was no indication that they varied across the UMDA site.

- For the second step of the analysis, the variable having the greatest affect in step one, hydraulic conductivity, was selected, and its effect on the extraction system and remediation time was evaluated. The base case for this step included a pumping scenario; the effect of hydraulic conductivity was measured by the necessary changes in the extraction system in order to remediate the site within the same time-frame. Only one variable was selected for this analysis because it was the parameter having the most effect on the pumping.

Sensitivity of the Plume to Hydrogeologic Parameters

The base case for this step was the simulated RDX plume developed in Section 2.3.2, Model Development, and presented in Figure 2-7. Using these plumes as the base case, ten runs were conducted in which only one variable was altered and the remaining variables remained consistent with the base case. The original values used in the base case are presented in Section 2.3.2, Model Development, and summarized in Table 2-11. Hydraulic conductivity varied by node and was altered through use of an array scaling factor.

Following each run, the size and length of the plume was measured (in number of nodes) and compared against the base case plume size and length. These factors were chosen because they indicate changes in the total plume volume which, in turn, affects the pumping rate and time necessary for remediation. Size was measured as the total number

Table 2-11
Summary of Model Sensitivity Comparison

MODEL RUN	LENGTH OF PLUME		AREA OF PLUME	
	Nodes	% change	Nodes	% change
Base Case	7		24	
Hydraulic Conductivity				
Run #1 - doubled	9	29%	30	25%
Run #2 - halfed	5	-29%	17	-29%
Effective Porosity				
Run #3 - doubled	6	-14%	18	-25%
Run #4 - halfed	7	0%	24	0%
Gradient				
Run #5 - doubled	9	29%	30	25%
Run #6 - halfed	6	-14%	18	-25%
Dispersivity				
Run #7 - doubled	7	0%	26	8%
Run #8 - halfed	6	-14%	22	-8%
Retardation				
Run #9 - doubled	5	-29%	16	-33%
Run #10 - halfed	8	14%	28	17%

NOTES:
1. Distance and area given in number of nodes
2. Distance = the maximum number of nodes along the length of the plume
3. % change = percent change from the base case value

of nodes that contained detectable concentrations of RDX. The length was measured as the total number of nodes in the primary direction of plume transport (the "Y-direction"). The results of the comparison are included on Table 2-11.

In general, the plume size and length increased with:

- increased hydraulic conductivity (transmissivity)
- increased gradient
- increased dispersivity
- decreased effective porosity
- decreased retardation

The plume size and length decreased with the reciprocal of the factors above. In some cases, the change in the parameter was insufficient to change the length and area from the base case. Hydraulic conductivity, gradient and retardation have a larger effect on the results of the model than do porosity or dispersivity. However, only in one case did either length or size change more than 30% from the base case (the plume length decreased by 33% when the RDX retardation factor was doubled). The parameter with the most influence on the final results is hydraulic conductivity, therefore, hydraulic conductivity was selected as the parameter for additional sensitivity analyses.

The accuracy of the sensitivity analysis is affected by the distance between the nodes (400 feet) and automatic rounding of the concentrations. For example, the total plume length in the base case is 2,800 feet (7 nodes at 400 feet/node). Therefore, the smallest change observable in plume length is one node or 400 feet (14% of the base case length). The 400-foot grid size was necessary to reduce the effects of boundary conditions and allow for long transport distances. The maximum number of active transport cells in MOC is 20 by 20, so modeling the entire area resulted in a large grid spacing. The larger the grid spacing, the smaller the nodal area representing the plume. Therefore, for the model to accurately evaluate long transport distances, the plume needed to be represented by a minimum number of nodes. The precision of the sensitivity analysis is limited by the plume size (i.e., smaller changes would be observable if the plume were initially larger).

Rounding may also affect the accuracy of the analysis. In the base case the plume is 7 nodes long; however without a concentration of "1" in a single node, the plume would only be 6 nodes long. Given that the "1" is a rounded number, a very small change in the concentration at that node could change the plume length to 6 nodes. However, the purpose of the first step of the analysis was to identify a parameter for Step 2, thus the relative responses of the parameters on the plume are more important than the absolute changes from the base case.

Sensitivity of the Extraction Rate to Hydraulic Conductivity

A second, more elaborate, sensitivity analysis was conducted to evaluate the effect on the overall pumping rate of increasing or decreasing input parameters. One parameter, hydraulic conductivity, was selected for this analysis because it was the parameter having the greatest impact on contaminant distribution as shown in Step 1.

For the second analysis, the hydraulic conductivity was doubled and halved for the compounds RDX and TNT. The model was run under pumping conditions with three pumping wells located at nodes (20,18), (20,20), and (20,22). The pumping scenario was based on the 10-year PRG extraction criteria with a combined pumping rate of 333 gpm. For these runs, the MOC model simulation was divided into two parts, a 28-year contamination input period using the base case model parameters followed by a 10-year remedial simulation using the doubled and halved hydraulic conductivity values. The results of these modeling simulations indicated that for the doubled hydraulic conductivity simulation, RDX cleanup to PRG standards could not be achieved without raising the extraction rate at cell (20,22) from 0.08 to 0.2 ft^3/sec. This represents a 14 percent increase in overall pumping rate. For the model runs using half of the base case value of hydraulic conducted, TNT could not be cleaned up to PRGs in 10 years without raising the extraction rate at cell (20,18) by 0.05 ft^3/sec. This represents a 7 percent increase in overall pumping rate.

The sensitivity analysis was conducted on a variety of parameters to evaluate their influences on the plume size and therefore the pumping rate required for remediation. Based on the results of the analysis, even if the hydraulic conductivity, the parameter with the most effect, were to be either doubled or halved, the extraction rate would change by less than 15 percent.

2.4 Reinfiltration of Treated Ground Water into the Explosive Washout Lagoons

The selected remediation for the Explosive Washout Lagoon Soils, as presented in the 1992 ROD, involves excavating the soils beneath the lagoons to a depth of five feet (11 feet below the surface) while leaving the remaining soil contamination in place. Concerns have been raised about the contamination remaining within 10 feet of the ground water table because there is evidence that the ground water table is rising and that this contamination may represent a source of continuing ground water contamination. Because of these concerns this FS has investigated the potential for discharging treated ground water back into the washout lagoons and flushing the contamination from the soils into the ground water and collecting the contamination down gradient in ground water extraction wells. RDX and 2,4,6-TNT were used in the investigation because they represent the contaminants with the highest concentrations and the range of contaminant mobilities (RDX high, TNT low). For this reason, the other contaminants of concern were assumed to be flushed from the soil prior to RDX and 2,4,6-TNT.

The amount of time required to flush RDX and 2,4,6 -TNT from unsaturated soils beneath the north and south lagoons at Site 4 has been calculated using an analytical model developed by van Genuchten and Alves (1982). The model was developed by solving the one-dimensional convective-dispersive solute transport equation under the assumption of steady state flow conditions. That is, volumetric moisture content and volumetric flux are constant both spatially and temporally. Given these assumptions the differential equation describing one-dimensional chemical transport reduces to:

$$D\frac{\partial^2 c}{\partial x^2} - v\frac{\partial c}{\partial x} - R\frac{\partial c}{\partial t} = \mu c - \gamma \qquad (eq.\ 2\text{-}1)$$

where: c = solution concentration (mass/length^3).
x = distance (length)
D = dispersion coefficient (length^2/time)
v = interstitial or pore water velocity (length/time)
q = volumetric flow rate (length/time)
θ = volumetric moisture content
t = time
μ = rate constant for first order decay in the liquid and solid phases of the soil (1/time)
γ = rate constant for zero order production (mass/length^3/time)
R = Retardation factor

The assumption was made that no production or decay occurred such that equation 2-1 reduces to:

$$R\frac{\partial c}{\partial t} = D\frac{\partial^2 c}{\partial x} - v\frac{\partial c}{\partial x} \qquad (eq.\ 2\text{-}2)$$

Solutions to Equation 2-2 were obtained by applying the following initial and boundary conditions:

$c(x,0) = C_i$ (eq. 2-3)
$c(0,t) = C_o$ for $0<t\leq t_o$ (eq. 2-4)
$c(0,t) = 0$ for $t>t_o$ (eq. 2-5)
$\partial c/\partial x\ (L,t) = 0$ (eq. 2-6)

where: C_i = initial concentration (mass/length^3)
C_o = input concentration (mass/length^3)
L = soil column length (length)
t_o = duration of solute pulse (time)

Equation 2-3 indicates the initial concentration in the soil is constant, while equations 2-4 and 2-5 indicate the input concentration at the surface is a constant greater than zero until time t_o, and zero after time t_o respectively. Equation 2-6 indicates that the spatial rate of change of concentration remains constant, that is, the slope of the concentration versus distance curve is zero at each point in space and time.

Given the initial and boundary conditions in equations 2-3 through 2-6, the solution to equation 2-2 is:

$$c(x,t) = C_i + (C_o - C_i)\,A(x,t) \text{ for } 0<t\leq t_o \qquad \text{(eq. 2-7)}$$

$$c(x,t) = C_i + (C_o - C_i)\,A(x,t) - C_o\,A(x,t-t_o) \text{ for } t>t_o \qquad \text{(eq. 2-8)}$$

where:

$$A(x,t) = 1 - \sum_{m=1}^{\infty} \frac{2\beta_m \sin\left(\frac{\beta_m x}{L}\right) \exp\left[\frac{vx}{2D} - \frac{v^2 t}{4DR} - \frac{\beta_m^2 Dt}{L^2 R}\right]}{\beta_m^2 + \left(\frac{vL}{2D}\right)^2 + \frac{vL}{2D}} \qquad (\textit{eq. } 2\text{-}9)$$

and the eigenvalues β_m are the positive roots of the equation:

$$\beta_m \cot(\beta_m) + (vL)/(2D) = 0 \qquad \text{(eq. 2-10)}$$

Solutions to Equations 2-7, 2-8, 2-9, and 2-10 have been programmed in Fortran; for a complete listing of the code see van Genuchten and Alves (1982). The input variables to the program are as follows:

V = Interstitial or pore-water velocity
D = Dispersion coefficient
R = Retardation factor
t_o = Duration of tracer pulse added to profile
C_i = Constant initial concentration
C_o = Constant input concentration
TOL = Convergence criterion for series solution in Equation 2-9
XI = Initial distance for computer printout

DX = Increment in distance for computer printout
XM = Maximum distance for computer printout
XL = Length of soil column
TI = Initial time for computer printout
DT = Time increments for computer printout
TM = Final time for computer printout

The values for each input variable used in the cleanup calculations are listed below. The rationale for using each value is also provided.

Interstitial or pore-water velocity

This value was estimated by first calculating the expected specific discharge through the soil column beneath the lagoons. The specific discharge is calculated using the following equation:

$$\text{specific discharge} = Q/A \qquad \text{(eq. 2-11)}$$

where: Q = volumetric flow through the soil column (length^3/time)
A = cross sectional area of the soil column perpendicular to flow (length^2)

From the modeling studies used to determine aquifer pumping rates required to contain the ground water contaminant plume (see Section 2.3.3, Ground Water Model) Q was determined to be 77, 138, 200, and 333 gpm for the four cleanup scenarios. Three of the flow rates were used to determine soil flushing rates.

The 333 gpm flow rate was not used because of concern that the lagoons would not be able to handle a flow at that rate. There is no percolation rate data available for the lagoons and in order to make an estimate of the maximum discharge rate to the lagoons therefore a percolation rate of 2 min/inch was assumed because of the sandy soils and the yields from the aquifer. Using the assumed percolation rate and an effective porosity of 0.2 a saturated vertical hydraulic conductivity was calculated to be 0.5 feet per hour by dividing the porosity by the percolation rate and converting the units (U.S. Department of the Interior, 1978). A maximum discharge rate was then calculated by multiplying the surface area of the lagoons by the vertical hydraulic conductivity. The discharge rate was determined to be 333 gpm. The actual maximum rate was reduced by 40 percent because of the uncertainty in the percolation rate to give a rate of 200 gpm. Percolation tests should be performed during the remedial design, and the actual discharge rate should be set based on that rate.

For demonstration purposes the 200 gpm flow rate was used in the example calculations. The cross sectional area was determined by considering a soil column that lies directly beneath both lagoons. Therefore, the width corresponds to the distance from the north side of the north lagoon to the south side of the southern lagoon, and the length corresponds to the distance measured from the west side of the lagoons to the east side. The width of both lagoons is 66 feet (north lagoon is 39 feet and the south lagoon is 27 feet) and the length 80 feet with a corresponding cross sectional area is 5280 ft^2. Given the volumetric flow rate and cross sectional area, the specific discharge was determined to be 222 cm/day as follows:

specific discharge = (200 gal/min)/5280 ft^2 x (0.1336806 ft^3)/(1 gal)
= (0.0051 ft/min) x (30.48 cm)/(1 ft)
= 0.154 cm/min
= (0.154 cm/min) x (60 min/hr) x (24 hr/day)
= 222 cm/day

However, the parameter of interest is the interstitial pore velocity which, for the purposes of this study, is assumed to be the average linear velocity through the soil column calculated by dividing the specific discharge by the soil porosity. Given the specific discharge of 222 cm/day and dividing by the effective porosity of 0.2 (see Section 2.3.3, Model Development for derivation of effective porosity), resulted in an average linear velocity of 1,111 cm/day.

The interstitial pore-water velocity for each discharge rate are as follows:

Discharge Rate	**Interstitial Pore-Water Velocity**
77 gpm	428 cm/day
138 gpm	767 cm/day
200 gpm	1,111 cm/day

As a check, to determine if this velocity could actually occur in these soils the maximum velocity obtainable by these soils was estimated using Darcy's Law:

$$v = \frac{K\frac{dh}{dz}}{\phi} \qquad (eq.\ 2\text{-}12)$$

where: K = the soil hydraulic conductivity (length/time)
dh/dz = the hydraulic gradient
ϕ = soil porosity

Since the soil column is vertical the hydraulic gradient is 1 when the soil column is saturated and no ponding occurs at the surface. The hydraulic conductivity of 70,226 cm/day was calculated by using a transmissivity corresponding to the overburden aquifer of 0.4 ft^2/sec and dividing by the aquifer thickness of 15 feet and converting to cm/day as follows:

$$\begin{aligned} K &= (0.4\ \text{ft}^2/\text{sec})/(15\ \text{ft}) \\ &= (0.0267\ \text{ft/sec}) \times (30.48\ \text{cm})/(1\ \text{ft}) \times (3600\ \text{sec})/(1\ \text{hr}) \times (24\ \text{hr})/(1\ \text{day}) \\ &= 70{,}226\ \text{cm/day} \end{aligned}$$

Therefore, the maximum velocity for a saturated soil column would be:

$$\begin{aligned} v &= [(70{,}226\ \text{cm/day}) \times (1)]/[0.2] \\ &= 351{,}130\ \text{cm/day} \end{aligned}$$

This velocity is well above the calculated velocity of 1,111 cm/day associated with the 200 gal/min pumping rate.

Dispersion Coefficient

The dispersion coefficient is calculated as follows:

$$D = \alpha v + D^* \qquad \text{(eq. 2-13)}$$

where: α = dispersity (length)
D^* = coefficient of molecular diffusion ($length^2/time$)
v = interstitial pore velocity (length/time), as defined above

Given the relatively high hydraulic conductivity and associated flow rates through the soil column, the molecular diffusion can be considered negligible. The dispersity is a characteristic property of the porous medium. A typical value is 1/10 the total distance travelled through the soil column. The length of the soil column, 52.27 feet, was determined by averaging the depth to the water table in wells in the vicinity of the lagoons. The wells used were 9, 22, 23, 24, 25, 4-1, 4-12, 4-14, and 4-18. The average ground water table depth was calculated using data collected in these wells from May 1988 through November 1991 presented in Appendix B.6 of the RI (Dames & Moore, 1992a). Given this information, α was determined to be 5.2 feet (158.5 cm). Multiplying α by the velocity (1,111 cm/day at a discharge rate of 200 gpm) resulted a dispersion coefficient of 176,093 cm^2/day for a discharge rate of 200 gpm.

The interstitial pore-water velocity for each discharge rate are as follows:

Discharge Rate	**Dispersion Coefficient**
77 gpm	67,838 cm^2/day
138 gpm	121,570 cm^2/day
200 gpm	176,093 cm^2/day

Retardation factor, R for RDX = 2.575, R for TNT = 8.5
The retardation factor is calculated with the following equation:

$$R = 1 + [(\rho K_d)/\phi] \qquad \text{(eq. 2-14)}$$

where:
p = the bulk density of the porous media (mass/length^3)
K_d = distribution coefficient (mass chemical adsorbed/mass soil)/(mass of chemical in solution/length^3 of solution)
ϕ = soil porosity

The soil porosity of 0.2 and the bulk density of the porous media (1.5 g/cm^3) were taken from the RI and correspond to the values used for the aquifer beneath the site. The distribution coefficients for RDX (0.21 ml/g) and TNT (1.0 ml/g) were also taken directly from the RI (Table 4-16, pg. 4-95) and correspond to the mean of various K_d values collected across the site measured in the lab.

Duration of tracer pulse added to profile, $t_o = 0$
This value corresponds to the time duration associated with the input of contaminated water to the soil column. Since the water input to the system is assumed clean, this value has been set to zero.

Constant initial concentration, C_i for RDX = 109,524 μg/l, C_i for 2,4,6-TNT = 12,000 μg/l
This parameter corresponds to the average soil concentrations detected beneath the lagoons. The values were determined by averaging results from soil samples collected below 5 feet and above 50 feet in borings S4B-5, S4B-6, S4B-7, and S4B-8 which were taken within the lagoons. The average soil concentrations were 23.0 mg/kg for RDX, and 12.0 mg/kg for 2,4,6-TNT (Table 2-12). The soil concentrations were then converted to water concentration using the respective partition coefficients (K_d) of 0.21 ml/g for RDX and 1.0 ml/g for 2,4,6-TNT.

Constant input concentration, $C_o = 0$
This parameter corresponds to the concentrations of water input to the column. Since the water used to flush the soil column is assumed clean, this parameter value has been set to zero.

Convergence criterion for series solution in equation 2-9, TOL = 0.0001
The value of this parameter determines the extent to which the series solution in equation 2-9 will be summed. The value has been arbitrarily set but any value less than 0.01 has little effect on the final solution for this particular problem.

Table 2-12: 2,4,6-TNT and RDX Concentrations for Soil Borings within the Explosive Washout Lagoons

	2,4,6-TNT					RDX				
Soil Boring	Sd	St	Minimum detected (mg/Kg)	Maximum detected (mg/Kg)	Average of all detects (mg/Kg)	Sd	St	Minimum detected (mg/Kg)	Maximum detected (mg/Kg)	Average of all detects (mg/Kg)
S4B-5	10	12	3.02	24	11.4	12	12	2.73	33	18.3
S4B-6	9	12	1.11	27	11.0	12	12	4.76	150	23.5
S4B-7	11	11	0.80	34	10.1	11	11	2.78	93	38.1
S4B-8	12	12	0.61	38	15.3	9	12	1.67	29	11.6

Sd = The total number of samples in which the compound was detected.
St = The total number of samples which were analyzed for this compound.

Length of soil column, XL = 1593.19 cm
This value corresponds to the total length of the soil column beneath the lagoons. The length of the soil column, 52.27 feet, was determined by averaging the depth to the water table in wells in the vicinity of the lagoons. The wells used were 9, 22, 23, 24, 25, 4-1, 4-12, 4-14, and 4-18. The average water table depth was calculated using data collected in these wells from May 1988 through November 1991 presented in Appendix B.6 of the RI.

The remaining input parameters to the program are only for printout and do not require discussion.

Initial distance for computer printout, XI = 1,593 cm
Increment in distance for computer printout, DX = 0 cm
Maximum distance for computer printout, XM = 1,593 cm
Initial time for computer printout, TI = 1 day
Time increments for computer printout, DT = 1 day
Final time for computer printout, TM = 5,475 days

When running the program, concentrations were printed that corresponded to the bottom of the soil column (1593 cm or 52.3 ft) at various times (i.e., 0 through 5,475 days). After running the program the results were visually scanned to determine the number of days required to achieve the chemical's corresponding cleanup concentrations at the bottom of the soil column. The soil cleanup levels were based on concentrations in soil that would be protective of the ground water. For RDX and 2,4,6-TNT these ground water cleanup concentrations are as follows:

RDX	2.1 µg/l
TNT	2.8 µg/l

The results of the modeling are presented in Appendix B. The times required to achieve the cleanup concentrations are as follows:

Discharge Rate	Clean up Time for RDX	Cleanup Time for TNT
77 gpm	40 days	106 days
138 gpm	22 days	59 days
200 gpm	16 days	41 days

One of the concerns with the modeling of cleanup times is that the K_d value used in this study is too low for both RDX and TNT. Therefore, cleanup times were estimated using K_d values increased by a factor of 5. The resulting K_d values for each compound are 1.05 ml/g and 5.0 ml/g for RDX and TNT respectively. The retardation coefficients, that were used in the model, which are calculated using the K_d values are12.875 and 42.5 for RDX and TNT respectively.

In addition to the recalculation of the K_d values and the associated retardation coefficients, a new initial concentration was calculated. The new initial concentration was determined by using the average detected soils concentrations of 23.0 mg/kg for RDX, and 12.0 mg/kg for TNT, and dividing by the new K_d. The resulting new initial concentrations (CI) are 21.90 mg/l and 2.4 mg/l for RDX and TNT respectively.

Given the new K_d values, the resulting cleanup times associated with the three discharge rates was as follows:

Discharge Rate	**Cleanup Time for RDX**	**Cleanup Time for TNT**
77 gpm	173 days	448 days
138 gpm	97 days	250 days
200 gpm	67 days	173 days

For the FS, the soil cleanup times based on the higher K_d values were used in order to ensure that the evaluation of alternatives was based on a conservative design basis. The cleanup times should be refined during the remedial design based on percolation tests, and consideration should be given to running bench-scale flushing studies with actual washout lagoon soil and the limitations of the model, to further model the transport of the contaminants in the actual remediation. Because of the uncertainties surrounding the flushing of the contaminants from the soils, a detailed monitoring program will be needed during flushing to ensure that the RDX and 2,4,6-TNT are being removed and that the contaminants in the ground water are not being forced into currently uncontaminated regions of the aquifer by the mounding under the lagoons.

2.5 Identification and Screening of Technologies and Process Options

In this section, the technologies associated with the general response actions discussed in Section 2.2, General Response Actions, and typical process options for each technology are identified, and the results of the technology screening evaluation are presented. The screening was intended to eliminate inappropriate remedial options. The rationale for rejecting certain process options or entire technologies is presented here. Process options selected for further detailed evaluation are described in Section 2.5.3, Final Evaluation and Screening of Process Options.

A two-step screening process was used. The preliminary screening reviewed technical and regulatory implementability to eliminate clearly inappropriate options. Those candidate technologies that were found to be potentially applicable in the preliminary screening were carried to the second screening. The second screening evaluated the remaining process options in greater detail, based on the following three criteria:

- Effectiveness
- Implementability
- Cost

As stipulated in EPA guidance, the cost criterion played a limited role in the screening of the technologies and process options. Greater emphasis was placed on effectiveness and implementability, so that clearly effective and implementable remedial technologies were retained for further detailed analysis. Only relative capital and operating and maintenance costs were considered, with evaluations made on the basis of engineering judgement. The detailed analysis develops remedial costs in greater depth in order to provide guidance for the effective development of a ROD.

2.5.1 Criteria for Identification and Screening of Remedial Technologies

Four factors were used to screen the identified technologies:

- Waste characteristics
- Site characteristics
- Technology characteristics
- Regulatory agency preferences

2.5.1.1 Waste Characteristics. Within Site 4 (Explosives Washout Lagoons), the ground water has been found to be contaminated with seven specific types of explosives, and explosive-related compounds, including: RDX; 1,3,5-TNB; 1,3-DNB; 2,4,6-TNT; 2,4-DNT; HMX; and nitrobenzene (See Table 2-1). Specific waste characteristics identified that could potentially influence the screening process include:

Reactivity

Military regulations and prudence dictate that technologies considered for remediation mitigate the possibility of a detonation. Reactivity studies performed for USATHAMA (Arthur D. Little, Inc., 1987) identified that a concentration of explosives in soil of 12 percent by weight is the minimum concentration at which detonation would occur. As a conservative guideline, AEC has adopted a 10 percent concentration as the minimum at which reactivity would be a concern. However, reactivity will be addressed as necessary for those technologies that involve processes that concentrate or accumulate explosives from the groundwater.

Volatility

As shown in Table 2-13, the ground water contaminants at Site 4 generally have low vapor pressures at ambient temperatures.

Aqueous Phase Solubility

As shown in Table 2-13, the contaminants are relatively insoluble in water.

Ground Water Volume Requiring Remediation

The total ground water volume to be remediated may affect the selection of the best remediation technology. Estimates of flowrates of contaminated ground water wells at Site 4 were calculated using the MOC model and are presented in Section 2.3.

2.5.1.2 Site Characteristics. Site characteristics that influence the screening and evaluation of alternatives include:

Location and Accessibility

UMDA is located in a rural setting. Site 4 is located in the east - central portion of the installation. Roads are located adjacent to the area to be remediated. There are no severe space limitations imposed by structures or geophysical barriers.

Security

UMDA is fenced and guarded 24 hours a day. It is expected that UMDA will retain its status as a restricted-access military installation at least through the 1990s. But UMDA's presence in the base closure program indicates that UMDA Site 4 ownership and access could change during a long-term groundwater treatment remedy.

Proximity to Potential Receptors

Military and civilian personnel assigned to UMDA are the only reasonable nearby receptors to any surface contamination at this time because of the limited access and distance from civilian populations. No ground water receptors exist currently because alluvial ground water is not used or planned to be used at UMDA.

Resource Availability

Electrical service is available for use at Site 4. The site does not have natural gas service. Water can be supplied from the installation hydrant system. However, the substantial irrigation needs of the region combined with the semi-arid climate limit the acceptability of remedial action alternatives that would require large volumes of water. Lined evaporation basins located at UMDA are available to dispose of limited quantities of wastewater. These ponds were originally constructed to contain well purge water and decontamination water from the ground water monitoring program.

Surface Conditions

Site 4 is partially covered by the two explosive washout lagoons, with surrounding areas covered with grasses and low brush. Some areas may be devoid of vegetation due to past or present disposal activities.

Table 2-13: Physical and Chemical Properties of the Explosives

	TNT	2,4-DNT	2,6-DNT	TNB	DNB	RDX	HMX	Tetryl
CAS Registry No.	118-96-7	121-14-2	606-20-2	99-35-4	99-65-0	121-82-4	2691-41-0	479-45-8
Empirical Formula	$C_7H_5N_3O_6$	$C_7H_6N_2O_4$	$C_7H_6N_2O_4$	$C_6H_3N_3O_6$	$C_6H_4N_2O_4$	$C_3H_6N_6O_6$	$C_4H_8N_8O_8$	$C_7H_5N_5O_8$
Molecular Weight	227.15	182.15	182.15	213.12	168.12	222.15	296.20	287.17
Density (g/cm^3)	1.65	1.521	1.538	1.63	1.575	1.83	1.90 (ß form)	1.73
Melting Point (°C)	80.75	72	66	122	90	205	286	129.5
Vapor Pressure (mm Hg, 25°C)	$5.51x10^{-6}$	$2.17x10^{-4}$	$5.67x10^{-4}$	$3.03x10^{-6}$	$1.31x10^{-4}$	$4.03x10^{-9}$	$3.33x10^{-14}$	$5.69x10^{-9}$
Aqueous Solubility (mg/L, 25°C)	150	280	206	385	533	60	5	80
Henry's Constant (atm.m^3/mole, 25°C)	$1.10x10^{-8}$	$1.86x10^{-7}$	$4.86x10-^{7}$	$2.21x10^{-9}$	$5.44x10^{-8}$	$1.96x10^{-11}$	$2.60x10^{-15}$	$2.69x10^{-11}$
Log K_{ow}	2.00	1.98	1.89	1.18	1.49	0.87	0.26	1.65
K (mL/g)	1.00	0.68	0.21	2.23	0.45	0.21	0.44	0.71
R	4.48	3.34	1.72	8.72	2.55	1.73	2.51	3.46
Biological concentration factor (BCF) (fish)	8.95	10.6	9.82	2.65	4.70	1.50	0.49	6.31

Source: Dames & Moore, 1992a

Geology

A description of the site geology is given in Section 1.2.1.2, Regional and Installation Setting.

2.5.1.3 Technology Characteristics. General technology characteristics that contribute to technology screening and evaluation include:

In Situ versus Ex Situ Treatment

For ground water remediation, in situ treatment provides the advantage of implementing the technology without having to pump water to the surface or excavate the soil, thereby reducing potential for exposure, as well as, in some instances, reducing costs. However, in situ technologies are limited by the need to be able to perform the treatment uniformly throughout the highly mobile ground water and, equally important, by the need to provide evidence of completeness and permanence of the remediation. For most in situ technologies, effectiveness is very dependent on site-specific features such as geology, hydrology, soil characteristics, and contaminant characteristics.

On-Site versus Off-Site Treatment

The NCP specifies a preference for on-site remedies as opposed to off-site remedies. On-site remediation may eliminate the need to apply for and obtain local, state, and federal permits - although it does not preclude meeting the substantive requirements of the permit regulations. Other advantages of on-site remediation include:

- The waste generator retains greater control of the waste and residues
- Costs of transportation are minimized
- Potential for spread of contamination and personal exposure are reduced

Costs of on-site treatment may be less than off-site treatment - particularly if there is a sufficient waste volume. In cases where the volume of waste to be treated is small, on site treatment costs may be higher than off-site because of the costs required to mobilize a treatment system on site.

Off-site treatment and disposal relieves the waste generator of the responsibility for meeting the substantive requirements for waste treatment and disposal facilities. However, the generator retains future liability for those wastes treated off site. This liability extends to treatment residuals, although the generator has little control over the management or disposition of the residuals.

An additional disadvantage of off-site treatment over on-site treatment is the increase in short-term risks due to the increased potential for public exposure and environmental damage in the event of spills or mishaps during transportation of the waste off site.

2.5.1.4 Regulatory Preferences. Section 121(b) of CERCLA mandates that, where possible, remedies that "utilize permanent solutions and alternative treatment technologies or resource recovery technologies to the maximum extent practicable" should be selected. Remedial actions in which treatment "permanently and significantly reduces the volume, toxicity, or mobility of hazardous substances, pollutants, and contaminants as a principal element" are preferred. This regulatory requirement influences the selection of applicable remedial technologies and must be factored into technology screening decisions.

2.5.2 Preliminary Screening

Figure 2-9 shows the general response actions presented in Section 2.2, General Response Actions, as well as possible technologies and process options. The technologies and process options shown were selected on the basis of previous experience remediating ground water. The results of the preliminary screening are shown in the figure by the shading of those technologies and process options that are not applicable to the cleanup of the ground water. Comments summarizing the reason for rejection are provided in the column farthest to the right.

Technologies and process options were initially screened by assessing whether or not they were conceptually viable with respect to the technical capabilities, regulatory preferences, and screening criteria presented in Section 2.5.1, Criteria for Identification and Screening of Remedial Technologies. A brief discussion of the important parameters and rationale behind particular screening decisions follows and is broken out by remedial technology.

2.5.2.1 No Action. The No Action alternative does not reduce human exposure or contaminant toxicity, mobility, or volume. However, as required by the NCP, it will be carried through subsequent screening and analysis as a viable option, where appropriate, to provide a baseline reference point for review and comparison of various alternatives.

2.5.2.2 Institutional Controls - Access Restrictions. Access restrictions are restrictions imposed on access to property or on the uses of the property. Such restrictions are imposed by legal instrument (e.g., laws, regulation, owner-imposed restrictive covenants in deeds). Access restrictions may be used for environmental or health protection concerns, for example, by restricting the placement of drinking water wells into a contaminated aquifer. Fencing and legal restrictions are two process options that are considered potentially applicable as part of an alternative because they can be used to limit exposure to the contamination and to limit pumping of ground water.

2.5.2.3 Institutional Controls - Ground Water Monitoring Program. A monitoring program of the ground water wells would be initiated to detect changes in the levels of contamination. Monitoring is not a suitable remedial technology by itself because it does not actively prevent exposure to contaminants, nor does it reduce contaminant toxicity, mobility, or volume. However, monitoring is commonly selected for further

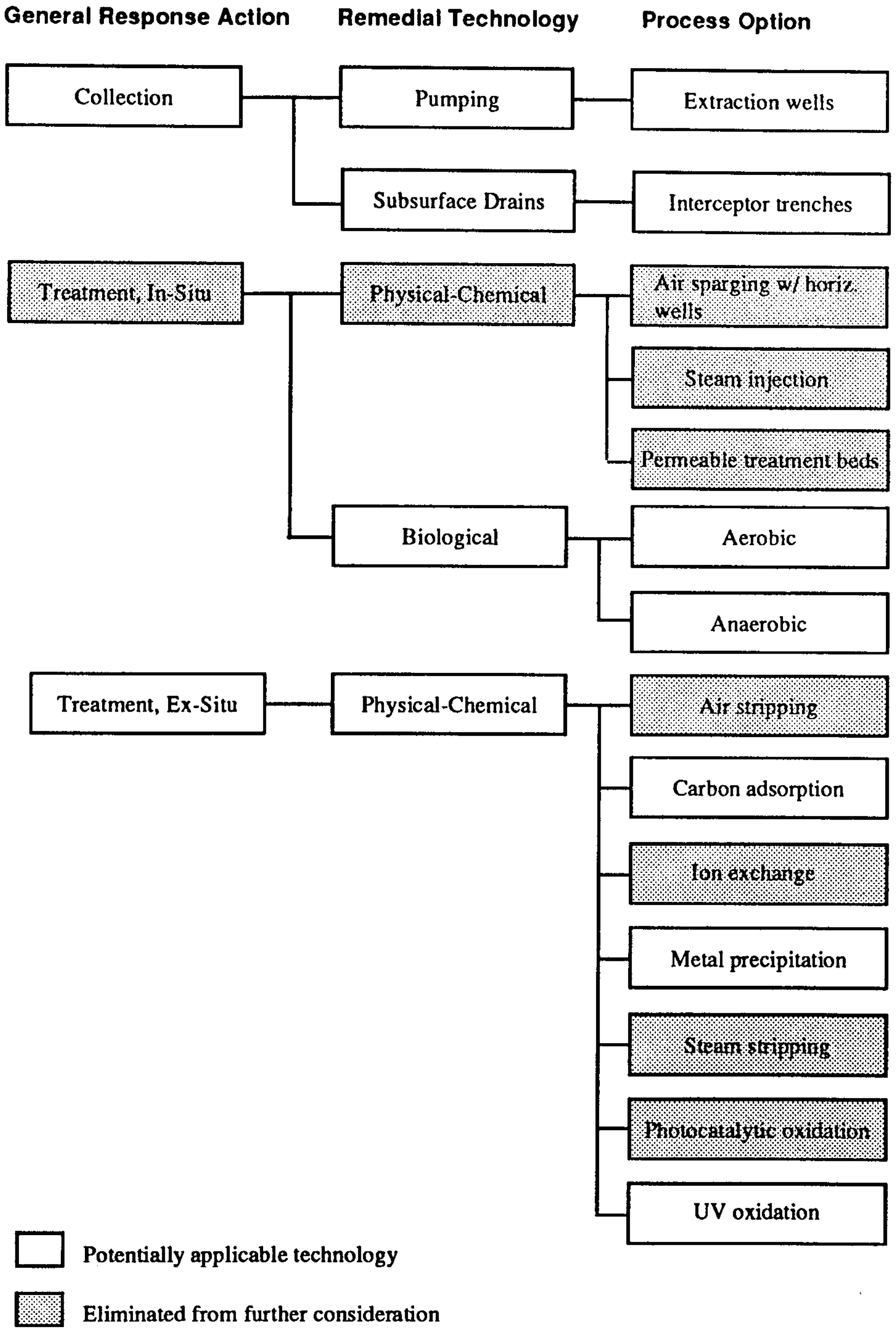
Figure 2-9: Initial Screening of Technologies and Process Options for Contaminated Ground Water

General Response Action	Remedial Technology	Process Option	Description	Screening Comments
☐ No Action	☐ Natural Attenuation	☐ Natural Attenuation	No action taken. However, the contaminants are naturally degraded through biological and abiotic reactions	Required for consideration by the National Contingency Plan
☐ Institutional	☐ Access Restrictions	☐ Fencing	Put fence around site	Potentially applicable as part of an alternative
		☐ Legal restriction	Legal restriction on the use of ground water	Potentially applicable as part of an alternative
	☐ Monitoring	☐ Ground Water Monitoring	Monitoring ground water to determine changes in extent of contamination	Potentially applicable as part of an alternative
▨ Containment	▨ Capping	▨ Engineered Cap	Install an impermeable layer over area	Not considered. Eliminated because it does not meet EPA's expectation of returning ground water to its beneficial use.
	▨ Vertical Barriers	▨ Grout curtain	Pressure injection of grout in a regular pattern of drilled holes	Eliminated due to highly permeable soils and depth of ground water.
		▨ Sheet barriers	Interlocking piles assembled and driven into the soil	Eliminated due to highly permeable soils and depth of ground water.
		▨ Slurry wall	Trench around areas of contamination and fill with a soil bentonite slurry	Eliminated due to highly permeable soils and depth of ground water.
		▨ Vibrating beam	Vibrating force to advance beams into ground with injection of slurry as beam is withdrawn	Eliminated due to highly permeable soils and depth of ground water.
	▨ Horizontal Barriers	▨ Block Displacement	In conjunction with vertical barriers, injection of slurry in notched injection holes	Eliminated due to highly permeable soils and depth of ground water.
		▨ Grout Injection	Pressure injection of grout at depth through closely spaced drilled holes	Eliminated due to highly permeable soils and depth of ground water.
		▨ Liners	Synthetic membrane/sheet under area	Eliminated due to highly permeable soils and depth of ground water.

☐ Potentially applicable technology

▨ Eliminated from further consideration

Figure 2. Initial Screening of Technologies and Process Options for Contaminated Ground Water (continued)

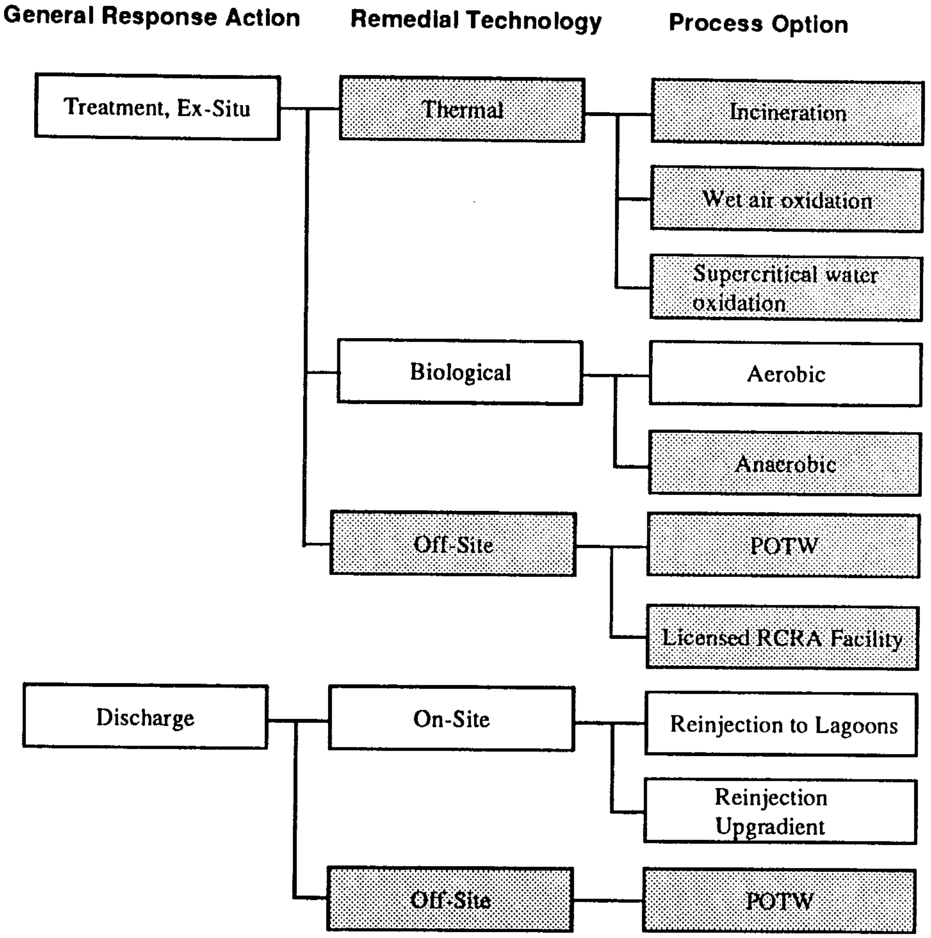


General Response Action	Remedial Technology	Process Option	Description	Screening Comments
Collection	Pumping	Extraction wells	Series of wells to extract contaminated ground water	Potentially applicable when completed with existing treatment
	Subsurface Drains	Interceptor trenches	Perforated pipe in trenches backfilled with porous media to collect contaminated water	Potentially applicable
▨ Treatment, In-Situ	▨ Physical-Chemical	▨ Air sparging w/ horiz. wells	Aerating water via horizontal wells to transfer contaminants to air and collection at vacuum extraction wells	Eliminated due to the lack of volatile contaminants
		▨ Steam injection	Thermal aeration of water to enhance volatilization of contaminants	Eliminated due to the lack of volatile contaminants
		▨ Permeable treatment beds	Down gradient trenches backfilled with GAC to absorb contaminants	Eliminated due to the large plume area and the high contaminant concentration and depth of contamination.
	Biological	Aerobic	Destruction of contaminants by aerobic microorganisms	Potentially applicable for the dilute region of the plume
		Anaerobic	Destruction of contaminants by anaerobic microorganisms	Potentially applicable for the dilute region of the plume
Treatment, Ex-Situ	Physical-Chemical	▨ Air stripping	Mixing air with water to transfer volatile contaminants to the air	Eliminated due to the lack of volatile contaminants
		Carbon adsorption	Adsorption of organic contaminants on activated carbon	Potentially applicable
		▨ Ion exchange	Use of ion exchange resins to remove ions from water to very low levels	Not applicable due to the high concentration of competing ions in the ground water
		Metal precipitation	Use of an additive to change the soluble metal salt to an insoluable salt	Potentially applicable for the background metals as pretreatment for explosives remediation
		▨ Steam stripping	Mixing of large volumes of steam with water to transfer VOCs to the air	Eliminated due to lack of volatile contaminants
		▨ Photocatalytic oxidation	Oxidation of organics using quantum energy from solar radiation or lasers	Eliminated because the technology is only in the very fundamental stages of development
		UV oxidation	Destruction of organic contaminants using UV light, ozone, and/or hydrogen peroxide	Potentially applicable

☐ Potentially applicable technology

▨ Eliminated from further consideration

Figure 2-9: Initial Screening of Technologies and Process Options for Contaminated Ground Water (continued)


General Response Action
Remedial Technology
Process Option
Treatment, Ex-Situ
Thermal
Incineration
Wet air oxidation
Supercritical water oxidation
Biological
Aerobic
Anaerobic
Off-Site
POTW
Licensed RCRA Facility
Discharge
On-Site
Reinjection to Lagoons
Reinjection Upgradient
Off-Site
POTW

General Response Action	Remedial Technology	Process Option	Description	Screening Comments
Treatment, Ex-Situ	Thermal	Incineration	Combustion of contaminants at high temperature	Eliminated because the contamination is too dilute
		Wet air oxidation	Oxidation of contaminants at relatively low temperature and high pressure	Eliminated because the contamination is too dilute
		Supercritical water oxidation	Oxidation of contaminants at high temperature and pressure	Eliminated because the contamination is too dilute
	Biological	Aerobic	Destruction of contaminants by aerobic microorganisms	Potentially applicable
		Anaerobic	Destruction of contaminants by anaerobic microorganisms	Not applicable due to high contaminant concentration
	Off-Site	POTW	Extracted water discharged to local POTW for treatment	Eliminated because the POTW is too far from the site
		Licensed RCRA Facility	Extracted ground water discharged to licensed RCRA facility for treatment	Eliminated due to the volume of ground water requiring treatment
Discharge	On-Site	Reinjection to Lagoons	Discharge of treated ground water to the Explosive Washout Lagoons	Potentially applicable
		Reinjection Upgradient	Reinjection of the treated ground water up gradient of the contamination.	Potentially applicable
	Off-Site	POTW	Discharge of the treated ground water to the local POTW	Eliminated because the POTW is too far from the site

☐ Potentially applicable technology

▨ Eliminated from further consideration

Source: Arthur D. Little, Inc.

consideration in combination with other remedies as a means to evaluate the short-term impacts and long-term effectiveness of those remedies. Therefore, monitoring is retained for further evaluation.

2.5.2.4 Containment - Site Capping. Capping was considered for remediation of the washout lagoons soils operable unit and was not considered under the ground water operable unit.

2.5.2.5 Containment - Vertical Barriers. Vertical barriers are subsurface, low permeability barriers that have been used for many years to control ground water flow. At Site 4, the vertical barriers could be used to confine the ground water plume away from or around the disposal area and generally control the potential for contaminant migration through the soil and/or ground water. The technical difficulty with using vertical barriers, such as slurry walls, at Site 4 is the porous basalt bedrock that is prevalent in the study area. The geologic structure of the bedrock makes it technically infeasible to seat the vertical barrier. Without a good seat, the ground water will leak under the barrier, and the barrier will not contain the contamination effectively. Therefore, vertical barriers have been eliminated from further consideration.

2.5.2.6 Containment - Horizontal Barriers. Horizontal barriers are subsurface, low permeability barriers that contain contamination from migrating vertically and contaminating the underlying aquifer. These barriers have been used for years in municipal and hazardous waste landfills to ensure that no contamination reaches the environment. At Site 4, this type of barrier would be ineffective because the contamination was discharged into lagoons many years ago, has had time to migrate, and has been in contact with the ground water for up to 35 years. A horizontal barrier has, therefore, been eliminated from further consideration.

2.5.2.7 Collection. A common consideration for remedial design engineering is whether to construct trenches to intercept ground water for treatment or to install closely spaced ground water extraction wells. Both systems have their unique advantages but at the same time, are both usually equally capable of achieving the same goal of ground water interception. Consequently, both systems (process options) have been retained for further evaluation.

Trench interception techniques typically consist of excavating a trench using a backhoe or, for deeper operations, a clamshell bucket, and emplacing a slotted pipe and/or gravel blanket at the base of the trench and backfilling with gravel. The gravel base or perforated pipe is generally sloped slightly to allow for consolidation of the intercepted ground water and/or contaminants at one side of the trench, usually in a sump. A pipe containing a submersible pump extends from ground surface to the base of the trench or to the slotted pipe. A submersible pump is activated to remove the accumulated liquids from the trench system. Depending on the trench length, it may be necessary to have several pump-out locations.

Extraction wells, that are designed to remediate a plume, are typically installed along a line parallel to the ground water flow when used to remediate ground water. The wells are generally constructed within a contamination plume using auger, cable tool, air rotary or mud rotary rigs that create boring in which the well screen, casing, screen pack, grout seal, and surface casing are placed. A submersible pump is placed at the base of the well and, as the well pumps, a ground water cone of depression is formed. Closely spaced wells will form overlapping cones of depression that can dewater affected areas and create hydraulic barriers to migration of contaminated ground water.

2.5.2.8 In Situ Treatment - Physical-Chemical. Physical treatment typically involves the transfer of contaminants from one medium to another, with or without concentrating the contaminant, for the purpose of facilitating final treatment or disposal. Three in situ physical/chemical remedial technologies were evaluated for use at Site 4:

- Air sparging
- Steam injection
- Permeable treatment beds

Air Sparging and Steam Injection

Air sparging and steam injection are similar in that they are designed to volatilize organic compounds from the ground water through the injection of a fluid (air or steam) and collect VOCs using vapor extraction. These processes are typically used at sites where the ground water contaminants are present in high concentrations. The only difference between the two technologies is that steam injection uses steam or hot air to assist in volatilizing the contaminants, and air sparging uses ambient air. The technologies are considered innovative, and as such, field testing data as to their ability to effectively remediate contaminated ground water are limited. Since the success of these methods depends on the volatilization of the contaminants, they are not appropriate for the contaminants at Site 4. Air sparging and steam injection in situ treatment relying on the volatilization of contaminants are therefore eliminated from further consideration.

Permeable Treatment Beds

Permeable treatment beds are trenches filled with activated carbon that the ground water must pass through. They are used mainly in situations where the contamination in the ground water is dilute or the volume is small, and the depth to the ground water is relatively shallow. At Site 4, the permeable beds option would not be effective because the size of the contaminated plume is extremely large and would require the construction of large very deep trenches and installation of significant amounts of activated carbon. In addition, the plume changes direction twice a year in response to irrigation drawdown which would require placement of the carbon beds in at least two locations. The permeable treatment beds are therefore eliminated from further consideration.

2.5.2.9 In Situ Treatment - Biological. The use of aerobic or anaerobic microorganisms to degrade contaminants in ground water is a potentially effective method for reducing the toxicity and mobility of explosive compounds. The two processes operate on the similar principle of adding nutrients and bacteria to the aquifer to enhance the locally available biological activity. Aerobic systems add oxygen and nutrients to the environment, and the bacteria use the contaminants for energy and growth, converting them to additional bacteria or carbon dioxide and water. Anaerobic systems operate in several different ways, from the addition of only nutrients or of methane and nutrients; however, the objective of each process is to enhance the reduction of the contaminants to nonhazardous compounds. Bioremediation is considered potentially applicable at Site 4 for the remediation of the explosives and is therefore retained for further consideration.

2.5.2.10 Ex Situ Treatment - Physical-Chemical. Physical treatment typically involves the transfer of contaminants from one medium to another, with or without concentrating the contaminant, for the purpose of facilitating final treatment or disposal. Chemical treatment involves the addition of a chemical (e.g., ozone, hydrogen peroxide) that causes the oxidation or reduction of the contaminant to form nonhazardous compounds that can be released to the environment. In the preliminary evaluation, five physical treatment technologies were reviewed:

- Air Stripping
- Carbon Adsorption
- Ion Exchange
- Metal Precipitation
- Steam Stripping

In addition, two chemical treatment technologies were reviewed:

- Photocatalytic Oxidation
- Ultraviolet Light (UV)/Oxidation

Air Stripping

Air stripping operates by stripping volatile compounds from the water into a gas stream. Contaminants are not destroyed by air stripping, but are physically separated from the aqueous solution. Contaminant vapors are transferred into the air stream and, then depending on the concentration, treated by incineration, adsorption, or catalytic oxidation. At Site 4, there are no volatile contaminants that could be removed from the ground water. Therefore, air stripping has been eliminated from further consideration.

Carbon Adsorption

Granular activated carbon (GAC) treatment is a physical process that removes a wide variety of contaminants by adsorbing them from the ground water stream. The contaminant adsorbs to the surface of the carbon until the GAC becomes exhausted (the contaminant of concern breaks through the carbon bed). When the GAC is exhausted, it can either be incinerated in a furnace at high temperatures where the contaminants are thermally oxidized; regenerated by steam desorption of the contaminants from the carbon followed by additional treatment of the contaminants; or disposed of as a hazardous waste. GAC has proven effective for all of the explosive contaminants at Site 4. Carbon adsorption is therefore retained for further evaluation. The performance of carbon should be unaffected by metals in the ground water. Metals removal is not expected to be needed.

Ion Exchange

Ion exchange like GAC treatment is a physical process that removes low concentration ionic compounds by adsorbing them from the ground water stream. The ionic contaminants are bound to the ion exchange resin by a charged site that has the opposite charge of the contaminant to be removed. When all the charged sites are loaded, the resin is exhausted and must be regenerated. Regeneration is performed by passing a concentrated ionic solution through the resin to exchange with the contaminants. The contaminants are then retained in the regenerant in a much more concentrated form than in the ground water. The contaminants can then be recovered or precipitated and disposed of as a hazardous waste. The large volume of ground water to be treated and the high concentration of contaminants will cause the active resin time to be very low; therefore, for practical purposes, ion exchange was eliminated from further consideration. Also, this process would remove only metals and this would be a pretreatment for explosives removal methods sensitive to metals.

Metal Precipitation

Metal precipitation from contaminated water involves the conversion of soluble heavy metal salts to insoluble salts that will precipitate. The precipitate can then be removed from the treated water by physical methods such as clarification and/or filtration. The heavy metal precipitation is simple, involving the addition of chemical reagents to adjust the pH of the contaminated water. Common reagents include:

- Alkalis such as lime, caustic soda, or magnesium hydroxide slurries to precipitate metal hydroxides.
- Sulfides such as sodium sulfide or ferrous sulfide slurries to precipitate metal sulfides.
- Precipitation of metals by xanthates is a new process. Xanthates are a family of compounds prepared by reacting an organic hydroxyl-containing compound with

sodium hydroxide and carbon disulfide. The resulting sodium xanthate reacts with metals to form insoluble metal xanthates in much the same way that sodium sulfide forms metal sulfides.

All three metal precipitation processes are considered applicable to Site 4 and are retained for further evaluation. This process would remove metals only and would thus be used as a pretreatment step for technologies that remove explosives.

Steam Stripping

Steam stripping operates by stripping volatile and some semivolatile compounds from the water into the gas stream. Contaminants are not destroyed by steam stripping, but are physically separated from the aqueous solution. Contaminant vapors are transferred into the air stream and, then depending on the concentration, treated by incineration, adsorption, or catalytic oxidation. At Site 4, the contaminants are all nonvolatile, therefore, steam stripping has been eliminated from further consideration.

Photocatalytic Oxidation

Photocatalytic oxidation is a photochemical process that oxidizes contaminants in a ground water stream to carbon dioxide and water. The photocatalytic process is performed by exposing the ground water to sunlight in the presence of a catalyst, titanium dioxide. The catalyst absorbs the high-energy photons, and reactive chemicals known as hydroxyl radicals are formed. These radicals are powerful oxidizers that break down the contaminant molecule. This technology, however, is still in its early development stage and has not been tested on a waste stream with explosives. It has therefore been eliminated from further consideration.

UV/Oxidation

UV/oxidation is a method of destroying organic contaminants in water by UV-catalyzed reactions with strong oxidizers such as hydrogen peroxide and/or ozone. Chemical oxidation of the contaminants occurs when the contaminant is allowed to react with a strong oxidizer. Although strong oxidizers themselves can render contaminants less toxic, the rate of the oxidation reactions is significantly increased through the addition of UV light. UV/oxidation has been successfully tested with many of the explosives (ICF Kaiser Engineers, 1993) found in the Site 4 ground water. The presence of background metals in the ground water will require that another technology, such as metals precipitation, be implemented in combination with UV/oxidation. This is necessary because metals will physically deposit onto the UV quartz tube causing a rapid decrease in the efficiency of the UV/oxidation method. UV/oxidation has been retained for further evaluation.

2.5.2.11 Ex Situ Treatment - Thermal. Thermal treatment involves oxidation at elevated temperatures of combustible organic compounds, or the volatilization of the contaminants at temperatures above ambient followed by the treatment of the volatilized contaminants by carbon adsorption, catalytic oxidation, or combustion in an afterburner. Three process options were considered (incineration, wet air oxidation, and supercritical water oxidation) for thermal treatment of the ground water, and all three technologies were eliminated because of the dilute nature of the ground water and the large volume of ground water. Also, incineration would be very costly due to the need to evaporate all of the extracted ground water and supercritical water oxidation has not been shown to be effective on explosives.

2.5.2.12 Ex Situ Treatment - Biological. Both aerobic and anaerobic ex situ biological processes were considered for the treatment of the ground water at Site 4. These biological processes have numerous reactor designs and slight variations on the operating parameters; therefore, one design was selected for each condition to be used for screening.

Aerobic

For the aerobic condition, a packed bed upflow column was assumed. This system, packed with GAC, is an innovative system that has proven effective in the treatment of wastewater and ground water streams where low contaminant discharge levels are required. The water stream is fed into the bottom of the bed, and the contaminants are absorbed into the biomass and onto the GAC. The bacteria metabolize the absorbed contaminants in the biomass and on the GAC. This process regenerates the GAC and allows it to continue to absorb contaminants. The ability of the bacteria to regenerate the GAC has not been proven in a full-scale test, and basic research is still being performed to determine the regenerative capacity of the biomass. However, even without regeneration, the biological packed bed has been shown to provide aerobic treatment for a number of the contaminants at Site 4 and has therefore been retained for further consideration.

Anaerobic

The anaerobic system considered in this FS is an upflow suspended bed reactor. The contaminated ground water is passed up through a high concentration of bacteria growing on suspended media. The bacteria adsorb the contaminants and degrade them under a reducing environment. This type of process has been tested largely in the laboratory under controlled conditions and has not been proven in the field. Because of the preliminary stage of development and the lack of field tests with the explosive wastes found at Site 4, this system has been eliminated from further consideration.

2.5.2.13 Ex Situ Treatment - Off-Site. Off-site treatment requires the collection and the transport of the ground water to an off-site facility for treatment and/or disposal. This option can be performed in two ways: to discharge the ground water to the municipal publicly owned treatment works (POTW), or to collect the ground water and transport it off site to a licensed RCRA facility.

At Site 4, the disposal of the untreated ground water to a POTW would not be possible for two reasons:

- There is no POTW connection within a reasonable distance of the site, making the piping of the ground water to a POTW both technically and administratively infeasible.

- The discharge of the water off site may lead to a lowering of the water level in the aquifer. This would be a concern because of the off-site irrigation requirements placed on the aquifer.

The disposal of the ground water at a licensed RCRA facility would also be infeasible because it would lower the aquifer level. In addition, the ground water contamination is dilute, which would create a potential for multi-year treatment. This would necessitate disposing of a quantity of water off site, which would not be economically feasible. Therefore, the disposal of the untreated ground water at a RCRA facility is eliminated from further consideration. The elimination of the disposal of the ground water at a RCRA facility does not, however, eliminate the use of the RCRA facility for highly concentrated liquid wastes or treatment residuals that cannot be disposed of in the on-site treatment processes.

2.5.2.14 Discharge - On-Site. Two alternatives for the on-site discharge of treated ground water were considered for Site 4: discharge of the treated ground water to the Explosive Washout Lagoons; and upgradient of the contamination. The discharge of the ground water to the Explosive Washout Lagoons will help to flush out any remaining soil contaminants and reduce the chance of future aquifer contamination due to long-term soil leaching. This option is not required to ensure the soil or ground water remedy is protective, but is thought to enhance the soil source removal at a minimal additional cost. The upgradient reinjection of the treated ground water would not affect the remaining contamination in the soil but might enhance the remediation of the contamination in the ground water by increasing the ground water flow upgradient of the plume. Reinjection of the treated ground water upgradient of the contamination and discharge of treated ground water to the Explosive Washout Lagoons are both considered to be technically and administratively feasible. Consequently, both options are retained for further evaluation.

2.5.2.15 Discharge - Off-Site. Discharge of the treated ground water to an off-site POTW has been eliminated for the same reasons that the discharge of untreated ground water to a POTW was eliminated (see discussion under Ex Situ Treatment – Off-Site).

2.5.3 Final Evaluation and Screening of Process Options

Figure 2-10 shows the general response actions, technologies and process options remaining after the preliminary screening. These technologies and process options were then evaluated, in greater detail, according to the criteria of effectiveness, implementability, and cost. Brief descriptions of each of these criteria are presented below. The effectiveness of the process options were evaluated based on: (1) the potential effectiveness of the process option in handling the estimated volume of ground water and meeting the remedial action objectives; (2) the ability to minimize or eliminate the potential impacts to human health and the environment during the construction and implementation phase; and (3) how proven and reliable the process is with respect to the contaminants and conditions at the site.

The implementability of the process option encompasses both the technical and administrative feasibility of implementing the option. Technical implementability was the major criterion used for screening the process options in the preliminary screening to eliminate those that were clearly not applicable to the contaminants or the contaminated media. Therefore, this evaluation places greater emphasis on the institutional aspects of implementability, such as the ability to obtain necessary permits for off-site actions; the availability of treatment, storage, and disposal services; and the availability of skilled workers to implement the technology.

The cost evaluation plays a limited role in the screening of process options. The costs that are developed are relative in nature and not detailed. These costs are usually developed based on engineering judgment, and each process is evaluated as to whether costs are high, medium, or low with respect to the other process options.

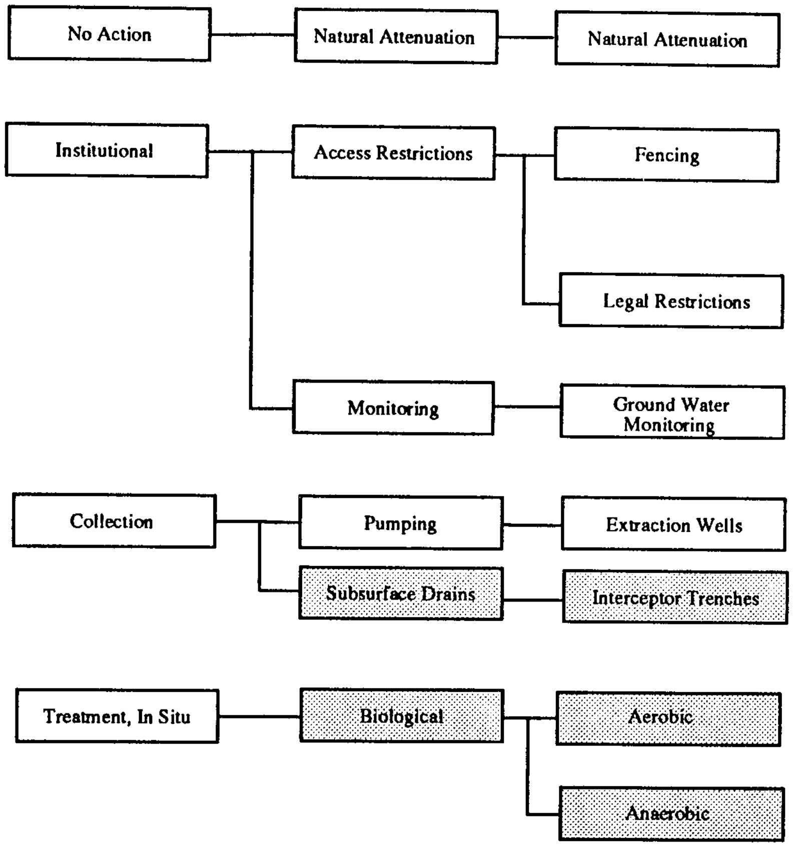
An evaluation of each of the response actions according to these evaluation criteria follows.

2.5.3.1 No Action. The No Action response involves no technology, requires no implementation, is not effective in reducing toxicity, mobility, or volume of the waste, and incurs no direct cost. Some natural degradation of organics might occur, however the rate of recovery is expected to be slow. This alternative is included as a requirement of the NCP and provides a baseline for comparison with the other technologies.

2.5.3.2 Institutional Controls - Access Restrictions. Two types of institutional controls have been considered for the remediation of the ground water at the Explosive Washout Lagoons. The first is a state or local legal restriction in the study area where contaminated ground water has been found. This legal restriction would have three purposes:

- Access restriction to the site to prevent direct human exposure to contaminants through legal limitations on who may conduct activities at the site.

Figure [illegible]: Applicable Remedial Technologies and Process Options for Ground Water



General Response Action	Remedial Technology	Process Option	Effectiveness	Implementability	Cost
No Action	Natural Attenuation	Natural Attenuation	Does not effectively reduce long-term risk or toxicity, mobility, or volume of the contamination; however, it is required by the NCP.	Technical and administrative implementation would be feasible.	There would be no capital or operating costs for this alternative.
Institutional	Access Restrictions	Fencing	Does not effectively reduce long-term risk or toxicity, mobility, or volume of the contamination; however, it does reduce short-term potential for human exposure with the contamination and a fence already exists around UMDA.	Technical and administrative implementation would be feasible.	Cost of fencing would be low.
		Legal Restrictions	Does not effectively reduce long-term risk or toxicity, mobility or volume of the contamination; however, it does reduce short-term potential for human exposure with the contamination.	Technical implementation would not be a concern; however, administrative implementation would require the state, the city, or the Army to provide a legal means for implementing restrictions.	Cost of legal restrictions would be low.
	Monitoring	Ground Water Monitoring	Monitoring is not an effective remedial technology; however, it is an effective means of ensuring that the remedies are operating effectively and meeting their goals.	Technical and administrative implementation of ground water monitoring is feasible.	The cost of ground water monitoring can be moderated by proper selection of wells to be tested.
Collection	Pumping	Extraction Wells	Extraction wells would be effective in intercepting the plume.	Technical implementation of extraction wells would be easier than an interceptor trench.	The capital cost of extraction wells would be low.
	Subsurface Drains	Interceptor Trenches	Interception trenches would be effective in intercepting the plume and would allow for inspection of the subsurface.	Technical implementation of an interceptor trench is more difficult than extraction wells.	The capital cost of an interceptor trench would be moderate.
Treatment, In Situ	Biological	Aerobic	Little is known of the effectiveness of bacteria to degrade explosives in the field due to limited field experience; therefore, a pilot test will be required.	Technical implementation is a concern since a large volume of ground water needs to be treated. Administrative implementation is feasible.	The capital cost of system would be low; however, costs could be increased due to the need for a pilot test.
		Anaerobic	Although some degradation is occuring on site, a field test program is necessary, since the effectiveness of anaerobic bioremediation is uncertain.	Technical implementation is a concern since a large volume of ground water needs to be treated. Administrative implementation is feasible.	The capital cost of system would be low; however, costs could be increased due to the need for a pilot test.

☐ Potentially applicable technology

▨ Eliminated from further consideration

Figure 2-10: Applicable Remedial Technologies and Process Options for Ground Water

General Response Action	Remedial Technology	Process Option	Effectiveness	Implementability	Cost
Treatment, Ex Situ	Physical-Chemical	Carbon Adsorption	GAC can effectively remove the contaminants, however, a large volume of carbon would be required and would have to be treated on site.	Technical and administrative implementation of the GAC system is feasible	The cost of the GAC system could be high since the spent carbon would have to be incinerated.
		Metal Precipitation	Hydroxide precipitation has been shown to be effective for the removal of dissolved metals. Sulfide or xanthate precipitation could be used if hydroxide precipitation did not meet PRGs.	Technical and administrative implementation of the metal precipitation system is feasible.	The cost of the metal precipitation system would be moderate since a high level of operator control is needed and the residual hydroxide sludge would have to be treated as hazardous waste unless otherwise tested.
		UV/Oxidation	UV/oxidation is an effective method of treatment of the explosives of concern and would be able to meet PRGs.	Technical and administrative implementation of UV/oxidation is feasible.	The capital cost of a UV/oxidation system is moderate compared to other ex situ treatment systems. The operating cost is also moderate due to the high use of electricity.
	▨ Biological	▨ Aerobic	The ability of aerobic biological remediation to meet the PRGs on a continued basis is unlikely since effluent concentrations below PRGs have not been attained.	Technical and administrative implementation of aerobic biological remediation is feasible.	The capital cost of an aerobic biological system would be moderate.
Discharge	On-Site	Reinfiltration Lagoons	Discharge to the lagoons is not a treatment method, but may decrease long-term ground water contamination by washing the soil and prevent contaminant leaching from the soil if the ground water table rises to historic levels.	Administrative implementation of discharge to the lagoons is feasible. The only technical concern is in relation to spreading the contaminant plume laterally into low permeability areas, which would increase the cleanup time.	The capital and operating costs of discharging treated ground water to the lagoons would be low in comparison to other water discharge options.
		Reinjection Upgradient	Reinjection is an effective ground water disposal method. However, the biannual change in water direction is a concern.	Technical and administrative implementation for the reinjection of the ground water is feasible.	The capital and operating costs of reinjecting treated ground water would be moderate to high in comparison to other water discharge options.

☐ Potentially applicable technology

▨ Eliminated from further consideration

Source: [illegible]hur D. Little, Inc.

- Land use restriction at the site to prevent future residential development where contaminants in the ground water are at concentrations greater than the preliminary remedial goals.

- Ground water restrictions to prohibit the installation of new wells in the contaminated portion of the plume and through the plume into the deep bedrock below the contamination. These restrictions may have to be expanded in the future to include restrictions on the existing ground water wells if any of the existing wells are found to be contaminated in excess of the preliminary remedial goals.

Possible restrictions could be placed on the installation of shallow irrigation wells near the plume where they could disrupt known plume movement and the efficiency of the remediation. No restrictions are thought to be needed on off-post wells due to their large distances from the site.

The legal restrictions would be maintained until the preliminary remedial goals are met or the site is determined not to pose a threat to human health or the environment.

The second form of institutional control would be fencing or another form of barrier to limit access to the contaminated areas of the site where there is a potential for direct exposure to the contamination. There is currently a fence around UMDA and access to the site is limited; however, if the site is released to the general public, a fence would not be necessary to ensure that incidental contact with ground water is avoided because the ground water is at depth, and does not breach the surface.

Effectiveness
The area of the site that would require legal restrictions is fairly large; however, it would be possible to effectively implement the access restrictions at Explosive Washout Lagoons. In addition there would be no short-term impact to human health or the environment while the controls were installed. Modeling has shown that natural attenuation will be an extremely long-term process. The difficulty with the institutional controls is that they will not effectively reduce the long-term risk associated with the ground water at the site, and they do not provide any reduction in the mobility, toxicity, or volume of the contamination. While the institutional controls do not provide long-term risk reduction they do provide a short-term reduction in the potential for humans to come into contact with the contamination; however, the EPA does not consider institutional controls to be an effective means of remediating ground water contamination because the ground water is not returned to its beneficial use in a reasonable time frame.

Implementation
Technically there is no reason that the institutional controls cannot be implemented at Site 4; however, administratively there is the necessity for the State of Oregon, Umatilla and

Morrow Counties, or the Army to provide the legal means for implementing the controls and to ensure that they are enforced.

Cost
The cost of the legal restrictions would be low.

Summary
Institutional controls would not be an effective long-term control for the site and do not provide any reduction in the mobility, toxicity, or volume of the contamination. The NCP has a stated expectation that contaminated ground water be restored to its beneficial use; therefore, institutional controls have been eliminated as a primary remedial alternative. Although the controls have been eliminated as a primary alternative they will still be necessary to prevent, to the extent practicable, human contact with the contamination while the site is being remediated.

2.5.3.3 Institutional Controls - Monitoring. A monitoring program of the ground water wells would be continued to ensure that the contamination does not move off the UMDA site.

Effectiveness
Monitoring is not a suitable remedial technology by itself because it does not actively prevent exposure to contaminants, nor does it reduce contaminant toxicity, mobility, or volume. However, monitoring is commonly selected for further consideration in combination with other remedies as a means to evaluate the short-term impacts and long-term effectiveness of those remedies.

Implementation
Monitoring of the ground water wells would not be technically or administratively difficult to implement.

Cost
The cost for monitoring the ground water wells should be moderate and be controlled by careful selection of which wells to monitor.

Summary
Monitoring is not a suitable remedial technology by itself because it does not actively prevent exposure to contaminants, nor does it reduce contaminant toxicity, mobility, or volume. However, monitoring is essential for the evaluation of short-term impacts and long-term effectiveness of remedial alternatives and to ensure that human health and the environment are being protected. Therefore, monitoring has been retained for further evaluation.

2.5.3.4 Collection. A common consideration for remedial design engineering is whether to construct trenches to intercept ground water for treatment or to install closely spaced ground water extraction wells. Both systems have their unique advantages; however, both are usually capable of achieving the same goal of ground water interception.

Trench interception techniques typically consist of excavating a trench using a backhoe or, for deeper operations, a clamshell bucket, and emplacing a slotted pipe and/or gravel blanket at the base of the trench and backfilling with gravel. The gravel base or perforated pipe is generally sloped slightly to allow for consolidation of the intercepted ground water and/or contaminants at one end of the trench, usually in a sump. A pipe containing a submersible pump extends from ground surface to the base of the sump to the slotted pipe. A submersible pump is activated to remove the accumulated liquids from the trench system. Depending on the trench length, it may be necessary to have several pump-out locations.

The advantage of a trench system is that it allows for visual inspection of the subsurface as the trench is excavated, and it ensures that the entire cross section of aquifer is actually intercepted. The disadvantages of a trench system are that at great depths, it becomes cost prohibitive compared to wells; there are technical limitations on excavation depths and geologic formations that can be readily penetrated; below the water table, it will be difficult to excavate; and the open hole during excavation can be dangerous if someone falls into it, or the walls collapse.

Extraction wells designed to remediate a plume, are typically installed within the plume often along a line parallel to the ground water flow. The wells are generally constructed using auger, cable tool, air rotary or mud rotary rigs that create a boring in which the well screen, casing, screen pack, grout seal, and surface casing are placed. A submersible pump is placed at the base of the well and, as the well pumps, a ground water cone of depression is formed. Closely spaced wells will form overlapping cones of depression that can dewater the affected areas.

The disadvantages of extraction wells are that little information is learned about the subsurface in comparison to trenches; vast changes in hydraulic conductivity, such as a major fracture between wells, will be difficult to dewater; and competing cones of depression may form stagnation zones. The advantages are that it is cost effective compared to trenches at greater depths and in competent formations, and may be the only viable technology for drainage more than a few feet below the water table.

Effectiveness

Both process options would be effective for the interception of the contaminated plume at UMDA, but the interceptor trench may provide less uncertainty with regard to its ability to contain the area because it allows for the inspection of the subsurface.

Implementation

The extraction wells would be much easier to implement at UMDA because of the lateral extent of the plume and the depth of the contamination. The installation of an interceptor trench would require the excavation of a large, very deep (e.g., 50 to 100 feet) trench in order to ensure that all the ground water was intercepted.

Cost

The cost of the extraction well system would be much less than the cost of the interceptor trench system because of the lateral extent of the plume and the depth of the contamination.

Summary

For the remediation of the ground water at the Explosive Washout Lagoons, extraction wells would be the preferred process option for long-term dewatering. Extraction wells will be more cost effective to install to depths on average of 30 feet, and, although hydraulic variations do occur, they should not be severe enough to create a ground water interception problem. If, however, extraction wells are found to be inappropriate during remedial design then interception trenches should be considered.

2.5.3.5 Treatment, In Situ - Aerobic Bioremediation. In situ aerobic degradation of the contaminants in the ground water is performed by extracting the ground water, adding nutrients (e.g., nitrogen, phosphorous, oxygen) and in some cases bacteria and reinjecting the ground water back into the aquifer with air or oxygen. The injected nutrients and bacteria once in the ground water oxidize the contaminants to form carbon dioxide and water. Aerobic bioremediation is a relatively simple process, but its actual effects on the explosives of concern are difficult to predict and have only recently improved as more actual field tests have been performed.

Effectiveness

The effectiveness of using aerobic bacteria to degrade the explosives is unknown due to the limited field data on the process.

Implementability

Technical implementation of aerobic bioremediation is a concern for the treatment of the ground water at the Explosive Washout Lagoons because of the large volume of the ground water that needs to be treated. The administrative implementation of aerobic bioremediation does not appear to be a concern.

Cost

The cost of implementing aerobic biodegradation would be relatively low in that there is not a significant amount of equipment that would be needed. The cost, however, would be increased due to the need for a field demonstration of the technology.

Summary
This process option has been eliminated from further consideration because the effectiveness of the aerobic bioremediation in degrading the explosive contaminants is uncertain due to the limited field experience with the process.

2.5.3.6 Treatment, In Situ - Anaerobic Bioremediation. Anaerobic bioremediation operates in a manner very similar to the operation of an aerobic remediation system. The ground water is extracted, nutrients are added, and the ground water is reinjected into the aquifer. The major difference is that no oxygen is added to the ground water.

Effectiveness
Some level of natural biological degradation of the contamination at Site 4 is likely currently occurring, but as can be seen by the continued sampling history at the site the process is quite slow. Enhancement of this process through the addition of nutrients may increase the degradation rate; however, because of the uncertainty surrounding the effectiveness of the anaerobic process a field test program would be needed.

Implementability
Technical implementation of anaerobic bioremediation is a concern for the treatment of the ground water at the Explosive Washout Lagoons because of the large volume of the ground water that needs to be treated. The administrative implementation of anaerobic bioremediation does not appear to be a problem.

Cost
The cost of implementing anaerobic biodegradation would be relatively low in that there is not a significant amount of equipment that would be needed. The cost, however, would be increased due to the need for a field demonstration of the technology.

Summary
This process option has been eliminated from further consideration because the effectiveness of the anaerobic process in degrading the explosive contaminants in situ to a less harmful compound is uncertain due to the limited field experience with the process.

2.5.3.7 Treatment, Ex Situ - Carbon Adsorption. Activated carbon adsorption is a process by which contaminants become physically and/or chemically attached to the surface of the carbon particles and are thereby removed from the gaseous or liquid stream, which passes through the carbon material unchanged. As such, carbon adsorption is a removal, not a destruction, technology. Activated carbon is made from a char of wood or coal and is "activated" by exposure to an oxidizing gas at high temperature. The activation process creates a porous structure within the carbon, resulting in a carbon material with a very high surface area to weight ratio. The surface properties of the activated carbon, which are critical to its ability to adsorb contaminants, are a function of the initial carbon source and the activation process. Activated carbon may be granular (particle diameter > 0.1 mm) or powdered (diameter < 200 mesh).

Typical granular activated carbon (GAC) systems consist of a fixed bed column containing the GAC material through which the contaminated media (liquid or gas) is passed, either in an upflow or downflow mode. Often, multiple columns are arranged in series or in parallel to achieve treatment and reduce or eliminate downtime. Design information for GAC systems include contact time, bed depth, carbon dosage, and pre-treatment requirements (e.g., metals or suspended solids removal). Powdered activated carbon is generally added directly to tanks of contaminated water with mixing followed by settling to achieve contaminant removal.

The amount of a contaminant that can be removed by GAC is determined by the adsorption capacity of the activated carbon. When the adsorption capacity is attained, the carbon bed will not adsorb additional material and the bed is considered to be “broken through” for that contaminant. When this occurs the "spent" carbon in the column must be removed and either replaced with fresh material or regenerated by burning off the contaminants. The spent carbon and contaminants may be thermal destroyed.

A variety of factors can affect the adsorption capacity of activated carbon: compound solubility (inversely related to adsorption capacity); temperature (inversely related); and pH (organic acids adsorb better at low pH, amino compounds adsorb better under high pH). In addition, chemical properties can also affect adsorption; high molecular weight aromatic and halogenated compounds adsorb better than aliphatic and low molecular weight compounds. The presence of many contaminant compounds in a single waste stream may also affect carbon adsorption system performance.

Regeneration would not be an option for the spent carbon from this site because the GAC will contain high concentrations of explosives. The high concentration of explosives is a concern because when the explosives combust the size of the GAC particles will be reduced. Therefore, off-site incineration of the carbon, rather than regeneration, will be evaluated as a treatment option for handling the spent carbon.

Effectiveness

All of the explosive contaminants at this site can be removed by GAC, and the adsorption capacities for most of the compounds are relatively high. The major concerns about the use of GAC is the amount of carbon that would be required to treat the large volume of ground water, the inability to regenerate carbon contaminated with explosives, and the risks and costs associated with transporting the spent carbon off site for incineration. Off-site incineration is the most common treatment system used for spent carbon contaminated with explosives at Army installations.

During preparation of the FS, we spoke with personnel from four Army Ammunition Plants that use commercial incineration facilities to dispose of spent GAC generated from the treatment of pink water. None of the personnel indicated that they had experienced problems with this disposal procedure.

Implementability
Technical and administrative implementation should not present a problem to the use of carbon adsorption. The substantive requirements of the State of Oregon drinking water and surface water regulations will need to be complied with for the reinjection of the ground water. Transportation permits may be needed depending on whether the spent carbon is sent off site for regeneration and disposal. The substantive requirements of the federal and state air regulations and RCRA would also have to be complied with if an off-site incineration system was used to handle the spent carbon.

Cost
Cost of the GAC system could be high because of the inability to regenerate the carbon and the need to treat the spent carbon off site by incineration.

Summary
GAC would be efficient for the treatment of ground water for explosives; however, the spent carbon would have to be treated off-site because regeneration is not possible. Because of its viability as a treatment option, carbon adsorption will be retained for further evaluation.

2.5.3.8 Treatment, Ex Situ - Metal Precipitation. Metal precipitation from contaminated water involves the conversion of soluble heavy metal salts to insoluble salts that will precipitate. The precipitate can then be removed from the treated water by physical methods such as clarification (settling) and/or filtration. For the metal precipitation process to be effective, it must be coupled with an efficient solids removal process. Other wise, metal precipitate solids may carry over into the effluent and negatively affect effluent quality and process efficiency.

The heavy metal precipitation step is simple, involving the addition of chemical reagents to adjust the pH of the contaminated water. The desired pH is one in which the metals exhibit low (or minimum) solubilities in water and therefore precipitate. This desired pH is dependent on the specific metal-reagent combination. Common reagents used include:

- Alkalis such as lime, caustic soda, or magnesium hydroxide slurries to precipitate metal hydroxides (hydroxide process)
- Sulfides such as sodium sulfide or ferrous sulfide slurries to precipitate metal sulfides (sulfide process)

A new process under development is precipitation of metals by xanthates. Xanthates are a family of compounds prepared by reacting an organic hydroxyl-containing compound with sodium hydroxide and carbon disulfide. The resulting sodium xanthate reacts with metals to form metal xanthates is much the same way that sodium sulfide forms metal sulfides.

At UMDA, the metal precipitation system would be used for two purposes:

- To remove any metal contamination that is found above the background concentrations.
- To remove any background metal contamination that may cause a problem with the operation of a downstream process option, such as UV/oxidation.

In order to meet these two objectives, the metal precipitation unit would have to remove: arsenic, calcium, cadmium, chromium, iron, and manganese. The most common and the safest system for the removal of these metals is hydroxide precipitation using either sodium hydroxide or lime. Because hydroxide precipitation is the most common system, it will be the process that will be evaluated; however, if hydroxide precipitation cannot meet the discharge limits then sulfide or xanthate precipitation should be considered.

Effectiveness

Hydroxide metal precipitation followed by flocculation and clarification has been shown to be effective for the removal of metal contamination and background metals at similar concentration as those found at UMDA. If hydroxide precipitation was not capable of meeting preliminary remedial goals, sulfide or xanthate precipitation could be considered to increase the percent removal.

Implementability

Both technical and administrative implementation of the metal precipitation process should not be a concern because it is a well demonstrated technology. The effluent from the metal precipitation system will be treated by another unit operation prior to being discharged; therefore, the only residual from the process will be the metal hydroxide sludge which will have to be tested to determine if it is hazardous or nonhazardous.

Cost

Cost of the metal hydroxide system would be moderate because these systems require a high level of operator control and the residual hydroxide sludge would have to be disposed of as a hazardous waste unless it is shown to be nonhazardous.

Summary

Hydroxide metal precipitation has been used extensively in industry and site remediation to remove soluble metal salts from process and ground water; therefore, the effectiveness of this system is well documented and the ability to implement the system should be straightforward. The only concern with the system is that it produces a residual hydroxide sludge that must be disposed of as a hazardous waste. Hydroxide metal precipitation has been retained for further evaluation.

2.5.3.9 Treatment, Ex Situ - UV/Oxidation. UV/oxidation is a method of destroying organic contaminants in water by UV-catalyzed reactions with strong oxidizers such as hydrogen peroxide and/or ozone. Chemical oxidation of the contaminants occurs when the contaminant is allowed to react with a strong oxidizer. Although strong oxidizers themselves can render contaminants less toxic, the rate of the oxidation reactions is significantly increased through the addition of UV light.

At Site 4, the first step of the process would be to extract the ground water from the aquifer and treat it for the removal of background metals by metal precipitation. The metals need to be removed in order to avoid their plating on the quartz tube in the UV reactor and decreasing the UV output intensity. After the metals have been removed, the ground water would be passed through the UV reactor where the oxidizer (either ozone or hydrogen peroxide) would be added. The treated ground water would then be discharged to the Explosive Washout Lagoons or reinjected back into the ground water, downgradient of the contamination.

Effectiveness
Review of the literature (ICF Kaiser Engineers, 1993) shows that UV/oxidation has been tested in several pilot plant studies, and is an effective method of treatment on the explosives of concern and would be able to meet the preliminary remedial goals. UV/oxidation is an innovative technology but it has been proven in full-scale operation and has been specified in several RODs. In addition, the use of UV/oxidation does not present any short-term problems that cannot be controlled through process design.

Implementability
Technical and administrative implementation should not present a problem to the use of UV/oxidation. One of the largest implementation problems for the use of UV/oxidation in the past has been the lack of vendors. This problem has been corrected over the past few years to the point where there are now four national vendors for the technology. The substantive requirements of the State of Oregon drinking water and surface water regulations will need to be complied with for the reinjection of the ground water and the regulations for air for the discharge of the off-gas to the environment if ozone is used.

Cost
The cost of a UV/oxidation system is moderate in comparison to the other ex situ ground water treatment systems. The operating cost of the system would also be moderate due to the high electric power requirements.

Summary
Literature reference (ICF Kaiser Engineers, 1993) results of the treatment of contaminants similar to those of concern at Site 4 show that UV/oxidation is an effective treatment option. It has therefore been retained for further evaluation.

2.5.3.10 Treatment, Ex Situ - Aerobic Bioremediation. For the aerobic condition, a packed bed upflow column was assumed in the preliminary screening. This system, packed with GAC, is an innovative system that has proven effective in the treatment of wastewater and ground water streams where low contaminant discharge levels are required. The water stream is fed into the bottom of the bed and the contaminants are absorbed into the biomass and onto the GAC. The bacteria metabolize the absorbed contaminants in the biomass and on the GAC. This process regenerates the GAC and allows the GAC to continue to adsorb contaminants. The ability of the bacteria to regenerate the GAC is not proven on a full-scale and basic research is still being performed to determine the regenerative capacity of the biomass. The low level of the preliminary remedial goals makes the use of biological treatment a concern because while some of the explosives will biodegrade, the effluent concentrations have not been below the preliminary remedial goals.

Effectiveness
The ability of aerobic biodegradation to meet the preliminary remedial goals on a continued basis is uncertain; while some of the explosives have been shown to biodegrade the effluent concentrations have not been below the preliminary remedial goals.

Implementability
There does not appear to be any technical or administrative implementation concerns.

Cost
The cost of the biological/GAC system would be moderate in comparison to the other ex situ treatment systems.

Summary
The aerobic biological treatment system is eliminated from further consideration based on concerns about biological degradation being able to meet the preliminary remedial goals.

2.5.3.11 Discharge - Reinfiltration to Explosive Washout Lagoons. This process option would involve discharge of the treated ground water to an on-site reinfiltration region in the Explosive Washout Lagoons. This would allow the treated ground water to flush the explosive contamination remaining in the soils after the implementation of the Explosive Washout Lagoon Soils ROD. The explosive contamination would then be collected in the downgradient extraction wells.

Effectiveness
This method of discharge may be used to wash the soil, which would decrease the long-term ground water contamination due to continued soil leaching. Discharge is not a method of treatment but rather an option for disposing of treated ground water. The effectiveness of using the treated ground water to leach the remaining explosive contamination from the soils appears to be moderate and would take a little over a year to remove 2,4,6-TNT (the least mobile contaminant). The soil remedy selected for the lagoons did not require the removal of low level explosives deep beneath the lagoons since the concentrations were low enough. Leaching through reinfiltration is being considered since it provides additional contaminant removal at minimal cost and ground water discharge must occur.

Implementability
There does not appear to be any administrative implementation problems. The technical implementability concern is in regard to the potential for lateral spreading of the contaminants into regions of low permeability due to the hydraulic driving force of the discharged water. To minimize this potential the treated ground water would only be discharged to the lagoons for a period of time long enough to flush the remaining soil contamination from the soils. After the contamination is removed the treated ground water would be reinfiltrated upgradient of the plume (See Section 2.5.3.12, Discharge - Reinfiltration Upgradient of Explosive Washout Lagoons).

Cost
The cost of the Explosive Washout Lagoons discharge option would be low in comparison to other discharge methods.

Summary
Reinfiltrating the treated ground water into the Explosive Washout Lagoons would be effective for flushing the remaining contamination from the soil. The only concern with the use of this process option is the potential for spreading the contamination into previously uncontaminated areas.

2.5.3.12 Discharge - Reinfiltration Upgradient of the Explosive Washout Lagoons. This method involves the reinfiltration of the treated ground water with the use of infiltration galleries approximately 800 feet upgradient of the washout lagoons.

Effectiveness
The reinfiltration of the treated ground water into the aquifer would be an effective disposal alternative for the Site 4 ground water.

Implementability
There does not appear to be any technical or administrative implementation problems.

Cost

The cost of installing infiltration galleries would be moderate to high in comparison to other discharge methods.

Summary

Reinjection of ground water as a method of on-site discharge is retained for further consideration; however, the biannual directional ground water flow should be reviewed when designing the infiltration system in the Remedial Design.

3.0 Development of Alternatives

In assembling alternatives, general response actions and the process options chosen to represent the various technology types were combined to form an overall method of treatment for the site. Consideration was also given to developing alternatives that provided for different time frames in which the site would meet the preliminary remedial action objectives and for different levels of protectiveness to human health and the environment.

The following process options were retained for the remediation of the ground water at the Explosive Washout Lagoons at the conclusion of the final screening:

- No Action
- Institutional Controls
  - Legal Restrictions
  - Monitoring
- Ex Situ Treatment – Physical/Chemical
  - Carbon Adsorption
  - Metal Precipitation
  - UV/oxidation
- Discharge
  - Reinfiltration to the Explosive Washout Lagoons
  - Reinfiltration Upgradient of the Explosive Washout Lagoons

These process options were then assembled into six distinct alternatives:

- Alternative 1 – No Action.
- Alternative 2 – Institutional controls will be placed on the contaminated ground water from the Explosive Washout Lagoons to restrict the ability to install ground water wells into the contamination. Monitoring will also be conducted.
- Alternative 3 - The ground water will be extracted from a series of wells over a 10- or 30-year period to remediate the aquifer to PRGs as shown in Table 2-6, Preliminary Remedial Goals for Ground Water. The ground water will be treated by hydroxide precipitation to remove the background metals from the contaminated ground water and then treated by UV/oxidation to destroy the explosives. Granular activated carbon will be used after the UV system to remove any remaining contaminants such as 1,3,5-TNB. After the ground water has been treated and it meets all the PRGs, it will be reinfiltrated into the Explosive Washout Lagoons for approximately one year to flush any explosive contamination from the soil. The

contamination removed from the soil will be collected in the ground water in the downgradient extraction wells. After the soil has been flushed, the treated ground water will be reinfiltrated 800 feet upgradient of the washout lagoons to minimize the risk of spreading the contamination.

- Alternative 4 - The ground water will be extracted from a series of wells over a 10- or 30-year period to remediate the aquifer to PRGs as shown in Table 2-6, Preliminary Remedial Goals for Ground Water. The ground water will be treated by granular activated carbon to remove the explosive contamination. The spent carbon will be sent off site for incineration or thermal treatment. After the ground water has been treated and it meets all PRGs, it will be reinfiltrated into the Explosive Washout Lagoons for approximately one year to flush any explosive contamination from the soil. The contamination removed from the soil will be collected in the ground water in the downgradient extraction wells. After the soil has been flushed, the treated ground water will be reinfiltrated 800 feet upgradient of the washout lagoons to minimize the risk of spreading the contamination.

- Alternative 5 - The ground water will be extracted from a series of wells over a 10- or 30-year period to remediate the aquifer to cleanup levels equivalent to an excess cancer risk of 1×10^{-4} or a hazard index of 1. The ground water will be treated by hydroxide precipitation to remove the background metals from the contaminated ground water and then treated by UV/oxidation to destroy the explosives. Granular activated carbon will be used after the UV system to remove any remaining contaminants such as 1,3,5-TNB. After the ground water has been treated and it meets all PRGs, it will be reinfiltrated into the Explosive Washout Lagoons for approximately one year to flush any explosive contamination from the soil. The contamination removed from the soil will be collected in the ground water in the downgradient extraction wells. After the soil has been flushed, the treated ground water will be reinfiltrated 800 feet upgradient of the washout lagoons to minimize the risk of spreading the contamination.

- Alternative 6 - The ground water will be extracted from a series of wells over a 10- or 30-year period to remediate the aquifer to cleanup levels equivalent to an excess cancer risk of 1×10^{-4} or a hazard index of 1. The ground water will be treated by granular activated carbon to remove the explosive contamination. The spent carbon will be sent off site for incineration. After the ground water has been treated and it meets all PRGs, it will be reinfiltrated into the Explosive Washout Lagoons for approximately one year to flush any explosive contamination from the soil. The contamination removed from the soil will be collected in the ground water in the downgradient extraction wells. After the soil has been flushed, the treated ground water will be reinfiltrated 800 feet upgradient of the washout lagoons to minimize the risk of spreading the contamination.

4.0 Detailed Analysis of Alternatives

This section presents a description and detailed evaluation of the six remedial alternatives presented in Section 3.0, Development of Alternatives.

The purpose of this section is to present information relevant to selecting an appropriate remedy for the ground water at the Explosive Washout Lagoons. The analyses were performed in accordance with the requirements of the NCP, CERCLA, SARA, and the Interim Guidance on Superfund Selection of Remedy. These analyses were also based on the institutional and technical criteria presented in Sections 2.0, Identification and Screening of Technologies and 3.0, Development of Alternatives.

4.1 CERCLA Evaluation Criteria

The detailed analysis of remedial alternatives consists of the evaluation and presentation of the relevant information that allows decision makers to select a site remedy. In developing this analysis, there are five specific statutory requirements for remedial actions that must be addressed:

- Protection of human health and the environment
- Attainment of ARARs (or providing grounds for invoking a waiver)
- Cost-effectiveness
- Use of permanent solutions and alternative treatment technologies or resource recovery technologies to the maximum extent practicable
- Preference for treatment that reduces toxicity, mobility, and/or volume as the principal element

In addition, CERCLA places an emphasis on evaluating long-term effectiveness and related considerations for each of the alternatives, including:

- The long-term uncertainties associated with land disposal
- The goals, objectives, and requirements of the Solid Waste Disposal Act
- The persistence, toxicity, and mobility of hazardous substances and their constituents, and their propensity to bioaccumulate
- Short- and long-term potential for adverse health effects from human exposure
- Long-term maintenance costs
- The potential for future remedial action costs if the alternative remedial action in question were to fail
- The potential threat to human health and the environment associated with excavation, transportation, and redisposal, or containment

Each of these requirements and considerations were then combined in the NCP, and nine evaluation criteria were developed to address the intent of the requirements and considerations. Other technical and policy considerations that have proven to be important for selecting remedial alternatives were also addressed. These nine evaluation criteria have served as the basis for conducting the detailed analysis of the alternatives for the remediation of ground water at the Explosive Washout Lagoons. In order to ensure that the appropriate weight was applied to each of the criteria, the NCP divides the nine criteria into three groups: (1) Threshold Criteria; (2) Primary Balancing Criteria; and (3) Modifying Criteria (Figure 4.1-1).

4.1.1 Threshold Criteria

Two of the criteria relate directly to statutory requirements that must ultimately be satisfied by the remedy. They are categorized as threshold criteria because any alternative selected to remediate the ground water must meet them. The requirements are:

- Overall Protection of Human Health and the Environment - Evaluates how each alternative, as a whole, achieves and maintains protection of human health and the environment. This assessment draws on the assessments conducted under other evaluation criteria, especially long-term and short-term effectiveness and compliance with ARARs. It focuses on whether a specific alternative achieves adequate protection and describes how site risks are eliminated, reduced or controlled through treatment, engineering, or institutional controls.

- Compliance with ARARs - Evaluates how each alternative complies with ARARs, or provides grounds for a waiver, if so justified. The assessment also addresses other information from advisories, criteria, and guidance that the agencies agree is "to be considered." The detailed analysis summarizes which federal and State of Oregon requirements are applicable or relevant and appropriate for the specific alternative and how the alternative meets these requirements.

4.1.2 Primary Balancing Criteria

Five of the criteria are grouped together because they represent the primary factors upon which the analysis is based, taking into account technical, cost, institutional, and risk concerns.

- Long-Term Effectiveness and Permanence - Evaluates the effectiveness of each alternative in maintaining the protection of human health and the environment after response objectives have been met. This assessment considers the magnitude of the residual risk (in this case, risks from ground water that is not treated and risk from treatment residuals, if any) measured by numerical standards, where possible. It also considers the adequacy and reliability of controls.

Figure 4.1-1: Criteria for Detailed Analysis of Alternatives

Threshold Criteria

OVERALL PROTECTION OF HUMAN HEALTH AND THE ENVIRONMENT

- How Alternative Provides Human Health and Environmental Protection

COMPLIANCE WITH ARARs

- Compliance with Chemical-Specific ARARs
- Compliance with Action-Specific ARARs
- Compliance with Location-Specific ARARS
- Compliance with Other Criteria, Advisories, and Guidances

Primary Balancing Criteria

LONG-TERM EFFECTIVENESS AND PERMANENCE

- Magnitude of Residual Risk
- Adequacy and Reliability of Controls

REDUCTION OF TOXICITY, MOBILITY, AND VOLUME THROUGH TREATMENT

- Treatment Process Used and Materials Treated
- Amount of Hazardous Materials Destroyed or Treated
- Degree of Expected Reductions in Toxicity, Mobility, and Volume
- Degree to Which Treatment is Irreversible
- Type and Quantity of Residuals Remaining After Treatment

SHORT-TERM EFFECTIVENESS

- Protection of Community During Remedial Actions
- Protection of Workers During Remedial Actions
- Environmental Impacts
- Time Until Remedial Action Objectives are Achieved

IMPLEMENTABILITY

- Ability to Construct and Operate the Technology
- Reliability of the Technology
- Ease of Undertaking Additional Remedial Actions, if Necessary
- Ability to Monitor Effectiveness of Remedy
- Ability to Obtain Approvals From Other Agencies
- Coordination With Other Agencies
- Availability of Necessary Equipment and Specialists
- Availability of Prospective Technologies

COST

- Capital Costs
- Operating and Maintenance Costs
- Present Worth Cost

Modifying Criteria

STATE ACCEPTANCE

COMMUNITY ACCEPTANCE

Source: EPA RI/FS Guidance Manual[3]

- Reduction of Toxicity, Mobility, and Volume Through Treatment - Evaluates the anticipated performance of the specific treatment technologies each alternative might employ. Where possible, numerical comparisons before and after remediation are presented. This assessment also considers the degree to which treatment is irreversible, the type and quantity of residuals that will remain following treatment, and the degree to which the treatment reduces the inherent hazards posed by the site.

- Short-Term Effectiveness - Examines the effectiveness of each alternative in protecting public health, worker health, and the environment during the construction and implementation of a remedy until response objectives have been met. The time until protection is achieved is also considered here.

- Implementability - Evaluates the technical and administrative feasibility of each alternative and the availability of required goods and services. Technical feasibility includes the ability to construct the system, the ability to operate and maintain the equipment, and the ability to monitor and review the effectiveness of operations. Administrative feasibility refers to the ability to obtain normal legal approvals (e.g., site access), public relations and community response, and coordination with government regulatory agencies.

- Cost - Evaluates the capital and operation and maintenance (O&M) costs of each alternative. Capital cost refers to the expenditures required to develop and construct the facilities necessary to implement the alternative. O&M cost refers to the expenditures of time and materials throughout the course of the project, including costs to lease equipment. These two categories of cost may be combined into a single cost figure using present worth analysis and a specified discount rate.

The level of detail required to analyze each alternative against these evaluation criteria depends on the type and complexity of the site, the type of technologies and alternatives being considered, and other project-specific considerations. This FS addresses a single site, one environmental media (ground water), and a range of contaminants that do not currently meet risk-based cleanup levels. The detail presented in the following analyses has been focused accordingly.

4.1.3 Modifying Criteria

In accordance with RI/FS guidance, the final two criteria involving state and community acceptance will be evaluated following the receipt of state agency and public comments on the FS and the Proposed Plan. The criteria are:

- State (Support Agency) Acceptance - Reflects the State of Oregon's apparent preferences among or concerns regarding the alternatives

- Community Acceptance - Reflects the local communities' apparent preferences among or concerns about alternatives

4.2 Individual Analysis of Alternatives

Each of the six remedial alternatives are presented in sufficient detail in the following sections to allow the evaluation of the alternatives against the nine NCP criteria. The State of Oregon's comments are incorporated into the entire RI/FS process due to the state's role as equal partner with the Army and the EPA in the UMDA Federal Facility Agreement. (Community Acceptance will not be evaluated until the public comment period.) Each alternative is briefly summarized and then described in more detail. In the instance of common process options between the alternatives, the common process option will only be presented in the first alternative and the reader will be referenced to the earlier presentation when the process option is discussed again. Operating and Maintenance calculations are presented in Appendix C.

A number of Remedial Design/Remedial Action planning documents may be required for implementation of a given alternative. These plans may include: Work Plan; Materials Handling Plan; Chemical Data Acquisition Plan; Trial Burn Plan; Erosion and Sedimentation Control Plan; Security Plan; Safety Plan; Traffic Control Plan; and Environmental Protection Plan. The extent and detail to which planning documentation will be required will depend on the specific processes to be employed in the remedial action and the complexity of the on-site remedial action activities. Based on previous remedial activities conducted by the Army, these costs are estimated at 10% of the total capital and O&M costs.

Each of the alternatives will require that a five-year review is performed. The objective of the five-year reviews is twofold: (1) to confirm that the remedy as presented in the ROD and/or remedial design remains effective for the protection of human health and the environment (e.g., the remedy is operating and functioning as designed, institutional controls are in place and are protective); and (2) to evaluate whether original cleanup levels remain protective of human health and the environment.

The focus of the five-year review would depend on the original goal of the response action. If protectiveness is being assured through exposure protection (e.g, containment with a cap) and institutional controls, the review would focus on whether the cap remains effective and the controls remain in place and are sufficient to assure protection. For a Long-Term Remedial Action (LTRA) (i.e., an ongoing remedial action that has not yet achieved the cleanup standards set in the ROD), the review would focus on both the effectiveness of the technology and the specific performance levels established in the ROD (e.g., performance of an extraction and treatment system for ground water).

The first objective of a five-year review would be accomplished primarily through a review of documented operation and maintenance of the site, a site visit, and limited analysis of site conditions. The second objective requires an analysis of newly promulgated or modified requirements of federal and state environmental laws to determine if they are ARARs and/or if they call into question the protectiveness of the remedy (NCP Section 300.430(f) (l)(ii)(B)(l)). For example, new federal or state MCLs may be promulgated at a more stringent level, calling into question the protectiveness of a ground water preliminary remedial goal set at the risk-based cleanup level. The state would be requested to identify state ARARs promulgated or modified since ROD signature that may have a bearing on the protectiveness of the remedy.

A further objective of the five-year review is to consider the scope of operation and maintenance (O&M) activities, the frequency of repairs, changes in monitoring indicators, costs at a site, and how this relates to protectiveness. If O&M activities either grow unexpectedly over time or are simply much greater than had been estimated at the time of remedy selection, the reviewer would analyze O&M activities and cost increases in an effort to determine if such increases are an early indicator of the deterioration of the remedy. Rising efforts or costs may indicate that excessive attention or activity is required to ensure that a remedy functions properly. This rise might be due to the deterioration or inefficiency of the remedy. In this case, repair or further actions may be necessary to protect against a higher than acceptable potential for remedy failure. Based on such an analysis, the Army and the EPA, in consultation with the state, would consider whether further actions should be taken to reduce increasing O&M activities. As appropriate, the Army may also propose additional response actions to reduce O&M activities or contain rising O&M costs.

4.2.1 Alternative 1 - No Action

No Action means that no response to contamination is made, activities previously initiated are abandoned, and no further active human intervention occurs. Natural attenuation of the contaminated media will occur over time through dilution, biological degradation, and abiotic degradation.

The No Action alternative would, however, require five-year reviews intended to evaluate whether the alternative remains protective of public health and the environment. The five-year reviews would be initiated five years after the start of the remedial action and continue until no contaminants remain at the site above levels that allow for unrestricted use and unlimited exposure.

4.2.1.1 Five-Year Reviews. This alternative would require five-year reviews intended to evaluate whether the alternative remains protective of public health and the environment. The five-year reviews would be initiated five years after the start of the remedial action and continue until no contaminants remain at the site above levels that allow for unrestricted use and unlimited exposure. These reviews would be identical to the reviews described for the No Action alternative (see introduction to Section 4.2, Individual Analysis of Alternatives).

4.2.1.2 Capital Cost. There will be no capital cost incurred during the implementation of this alternative.

4.2.1.3 Operating Cost. There will be a minimal cost associated with the five-year review element of this alternative; approximately $4,000 annually or a Net Present Value (NPV) of $81,000 over 300 years using a 5% interest rate.

4.2.1.4 NCP Evaluation Criteria. The degree to which the No Action alternative meets the NCP evaluation criteria is discussed below.

Overall Protection of Human Health and the Environment

This alternative does not enhance protection of current aquifer users, the environment, or future land use scenarios. The risks posed by the contamination in the ground water, a carcinogenic risk of $2x10^{-3}$ and a hazard index of 60, would remain at the current level.

In addition, the No Action alternative would not control the migration of the contamination and may present a risk of exposure to the current aquifer users when the contaminant plume reaches the UMDA boundary within an estimated 70 years.

Compliance with ARARs

This alternative does not comply with the expectations of the NCP in regard to returning the aquifer to its beneficial use in a reasonable period. The alternative also fails to comply with the NCP carcinogenic risk range of 10^{-4} to 10^{-6} and the noncarcinogenic hazard index of 1. Likewise, the alternative fails to remediate the contaminated aquifer to meet risk-based cleanup levels.

Long-Term Effectiveness

This alternative provides no long-term protection of human health and the environment, and the potential for direct exposure to future site users remains.

Reduction in Toxicity, Mobility, and Volume

The No Action alternative achieves no reduction in the toxicity, mobility, or volume of the contaminants present.

Short-Term Effectiveness

Since no remedial activities are conducted, there would be no short-term impacts to workers, the public, or the environment due to the implementation of this alternative.

Implementability

There is no technical reason that the No Action alternative could not be implemented. However, there are two administrative considerations in implementing this alternative. First, it is highly unlikely that the No Action alternative would be acceptable to the regulatory agencies or generate favorable response from the local communities. Second, existing levels of contamination would make legal restrictions on site site use like those already in place at UMDA.

Cost

There would be no capital costs associated and only a minimal operating cost, for the five-year reviews, associated with implementing the No Action alternative.

4.2.2 Alternative 2 - Institutional Controls

This alternative would place legal restrictions on the contaminated ground water from the Explosive Washout Lagoons to restrict the installation of ground water wells into the contaminated aquifer. The alternative would also require the continued monitoring of the ground water and five-year reviews.

4.2.2.1 Institutional Controls. While the ground water is being naturally attenuated, institutional controls would be needed to restrict access to the contaminated ground water. The access restriction would be a state or local legal restriction in the study area where contaminated ground water has been found. This legal restriction would have three purposes:

- Access restriction to the site to prevent direct human exposure to contaminants through legal limitations on who may conduct activities on the site.
- Land use restriction on the site to prevent future residential development where contaminants in the ground water are at concentrations greater than the preliminary remedial goals.
- Ground water restrictions to prohibit the installation of new wells in the contaminated portion of the alluvial aquifer or the basalt layers underlying the contamination. These restrictions would have to be expanded in the future to include restrictions on the existing ground water wells if any of these wells are found to be contaminated in excess of the preliminary remedial goals.

The legal restrictions would be maintained until the preliminary remedial goals are met or the site is determined not to pose a threat to human health or the environment.

4.2.2.2 Monitoring. The monitoring program for the Explosive Washout Lagoons' ground water has been designed based on the results of the RI and should be modified as natural attenuation occurs or as the plume area expands. The objective of the program would be twofold:

- To monitor for changes in contaminant concentrations
- To ensure that contaminants do not migrate off UMDA or restricted ground water area in excess of risk-based cleanup levels

The program would monitor the existing three aquifers. Each would be monitored on a quarterly basis for explosives and metals. The sampling frequency could be reduced if the quarterly monitoring results are found to be similar.

4.2.2.3 Five-Year Reviews. In addition to the monitoring of the ground water and the institutional controls, this alternative would also require five-year reviews intended to evaluate whether the alternative remains protective of public health and the environment. The five-year reviews would be initiated five years after the start of the remedial action and continue until no contaminants remain at the site above levels that allow for unrestricted use and unlimited exposure. These reviews would be identical to the reviews described for the No Action alternative (see introduction to Section 4.2, Individual Analysis of Alternatives).

4.2.2.4 Capital Cost. The capital cost for the institutional control alternative is estimated to be approximately $20,000 based on the need to develop and implement legal deed restrictions. These restrictions will require a hydrogeologist to define the zone of contamination and legal counsel to implement the jointly written restrictions.

4.2.2.5 Operating Cost. The annual operating cost for the Institutional Controls Alternative is approximately $49,700, as is presented in Table 4.2.2-1. Using the annual operating cost, the net present value (NPV) was calculated for a 300-year scenario using a 5% and a 10% interest rate.

		5% Interest Rate		10% Interest Rate	
Time Frame	Annual Cost	Discount Factor	NPV	Discount Factor	NPV
1-300 years	$0.05M	20.5	$1.0M	10.5	$0.5M

4.2.2.6 NCP Evaluation Criteria. The degree to which the Institutional Controls alternative meets the NCP evaluation criteria is discussed below.

Overall Protection of Human Health and the Environment

This alternative limits the potential for exposure to the contaminants by restricting the use of the contaminated aquifer. However, the contamination in the aquifer will be left in place and the reduction in the risk would be due to restriction and not to removal and treatment of the contamination.

Table 4.2.2-1: Annual Operating Cost for Institutional Control – Alternative 2

Item	Units	Units/ Year	Unit Cost (1993 Dollars)	Annual Cost (1993 Dollars)
Variable Costs				
Monitoring				
Sample Collection	hours	640	30	19,200
Supervision	hours	32	50	1,600
Sample Analysis	samples	152	150	22,800
Data Review and Reporting	hours	32	65	2,080
Five-Year Review (a)	hours	50	80	4,000
Annual Operating Cost				**$49,680**

Notes:

(a) – The cost for the Five-Year Review has been divided evenly over five years

Source: Arthur D. Little, Inc.

In addition, the Institutional Controls alternative would not control the migration of the contamination and may present a risk of exposure to the current aquifer users when the contaminant plume reaches the UMDA boundary within an estimated 70 years.

Compliance with ARARs

This alternative would not comply with the expectations of the NCP in regard to returning the aquifer to its beneficial use in a reasonable period of time. The alternative would comply with the NCP requirement to prevent carcinogenic risk greater than th erange of 10^{-4} to 10^{-6} and the noncarcinogenic hazard index of 1. Likewise, the alternative fails to remediate the contaminated aquifer to meet State of Oregon's preference for remediation of contamination to background levels or to meet the remedial cleanup levels.

Long-Term Effectiveness

This alternative provides limited long-term protection of human health and the environment by restricting the access to the contaminated ground water. However, the contamination would be left in place and the contaminant migration would not be controlled. Because of the lack of control the contamination would reach the UMDA boundary within an estimated 70 years and may become a risk to the community surrounding UMDA.

Reduction in Toxicity, Mobility, and Volume

The Institutional Controls alternative achieves no reduction in the toxicity, mobility, or volume of the contaminants present.

Short-Term Effectiveness

Since no remedial activities are conducted, there would be no short-term impacts to workers, the public, or the environment.

Implementability

There is no technical reason that the Institutional Controls alternative could not be implemented. However, there are two administrative considerations in implementing this alternative. First, it is unlikely that this alternative would be acceptable to the regulatory agencies or generate a favorable response from the local communities. Second, existing levels of contamination would place long-term restrictions on future-site use.

Cost

There would be a limited capital cost estimated at $20,000 associated with the alternative. This cost would include time for a hydrogeologist to review the zone of contamination and legal counsel to implement the jointly written legal restrictions. The total NPV operating cost would be approximately $0.8 million over 300 years for monitoring the ground water.

4.2.3 Alternative 3A - UV/Oxidation (30 Years, Remediated to Preliminary Remedial Goals)

In this alternative, the ground water will be extracted from a series of three wells over a 30-year period to remediate the ground water to preliminary remedial goals shown in Section 2.1.5, Preliminary Remediation Goals for Ground Water (2.1 μg/L for RDX and 2.8 μg/L for TNT). The ground water will be treated by hydroxide precipitation to remove the background metals from the contaminated ground water and then treated by UV/oxidation to destroy the explosives (Figure 4.2.3-1). The results of a recent treatability study conducted at the Milan Army Ammunition Plant (ICF Kaiser Engineers, 1993), which has a ground water contaminant chemistry similar to that at Umatilla, indicate that it is not economically feasible to utilize UV/oxidation for complete contaminant destruction. Therefore, granular activated carbon (GAC) with off-site incineration, or another off-site thermal treatment (e.g., regeneration, cement kiln), of the spent carbon will be included as a polishing step to the primary UV/oxidation treatment.

After the ground water has been treated and meets the preliminary remedial goals, it will initially be pumped to the explosive washout lagoons, where it will be allowed to reinfiltrate into the soils under the lagoons. Reinfiltration of the treated ground water into the lagoons will flush the remaining soil contamination into the ground water table, where it will be collected downgradient in the extraction wells. After approximately eight months the reinfiltration of the treated ground water will be moved to infiltration galleys 400 to 800 feet upgradient of the lagoons (north-west).

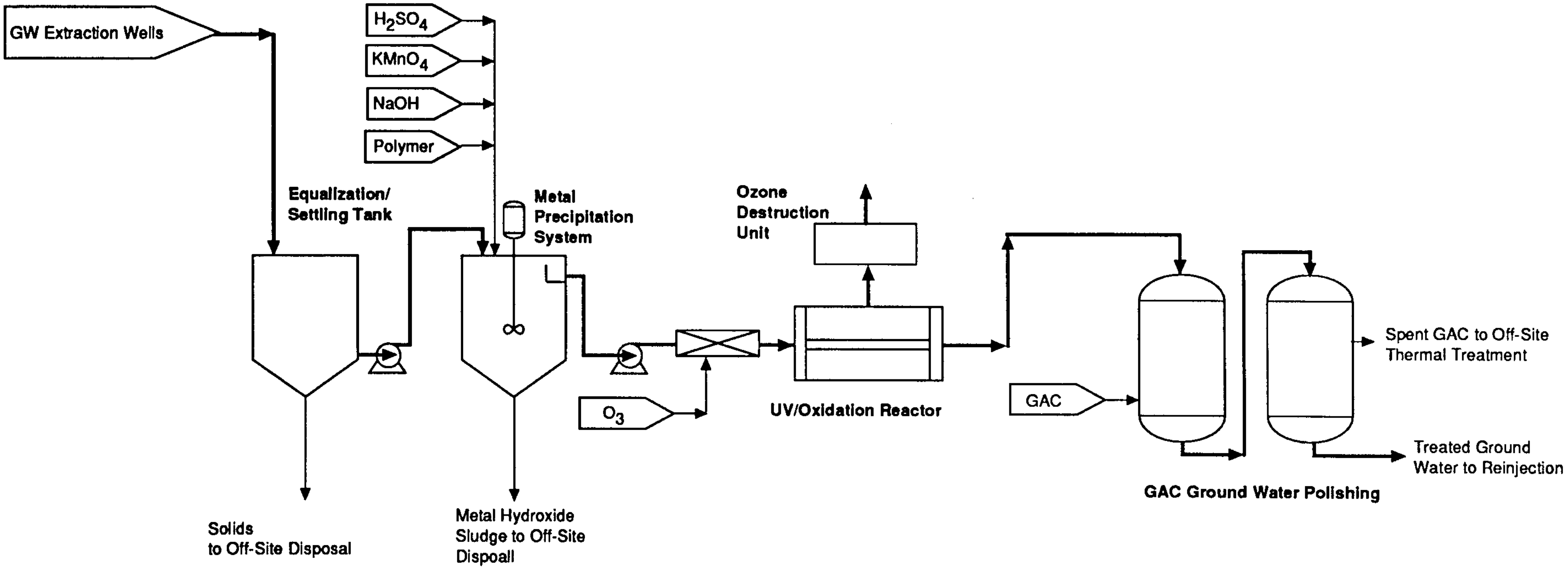
In addition, this alternative will require ground water monitoring, five-year reviews, and institutional controls, which will continue until the contamination has been remediated to the detection limits stated above.

4.2.3.1 Institutional Controls. While the ground water is being remediated, institutional controls will be needed to restrict access to the contaminated aquifer, the contaminated ground water remediation equipment and the interconnecting piping. The level of institutional control is similar to that previously discussed in Section 4.2.2, Alternative 2, and will not be repeated here.

4.2.3.2 Monitoring. The monitoring program would sample the existing monitoring wells and is identical to the program presented in Section 4.2.2.2, Monitoring, for the Institution Controls Alternative.

4.2.3.3 Five-Year Reviews. In addition to ground water monitoring and institutional controls, this alternative would require five-year reviews intended to evaluate whether the alternative remains protective of public health and the environment. The five-year reviews would be initiated five years after the start of the remedial action and continue until no contaminants remain at the site above levels that allow for unrestricted use and

Figure 4.2.3-1: Conceptual Flow Diagram of UV/Oxidation of Contaminated Ground Water


GW Extraction Wells
H_2SO_4
$KMnO_4$
NaOH
Polymer
Equalization/ Settling Tank
Metal Precipitation System
Ozone Destruction Unit
O_3
UV/Oxidation Reactor
GAC
Spent GAC to Off-Site Thermal Treatment
Treated Ground Water to Reinjection
GAC Ground Water Polishing
Solids to Off-Site Disposal
Metal Hydroxide Sludge to Off-Site Dispoall

Source: Arthur D. Little, Inc.

unlimited exposure. These reviews would be identical to the reviews described for the No Action alternative (see the introduction to Section 4.2, Individual Analysis of Alternatives).

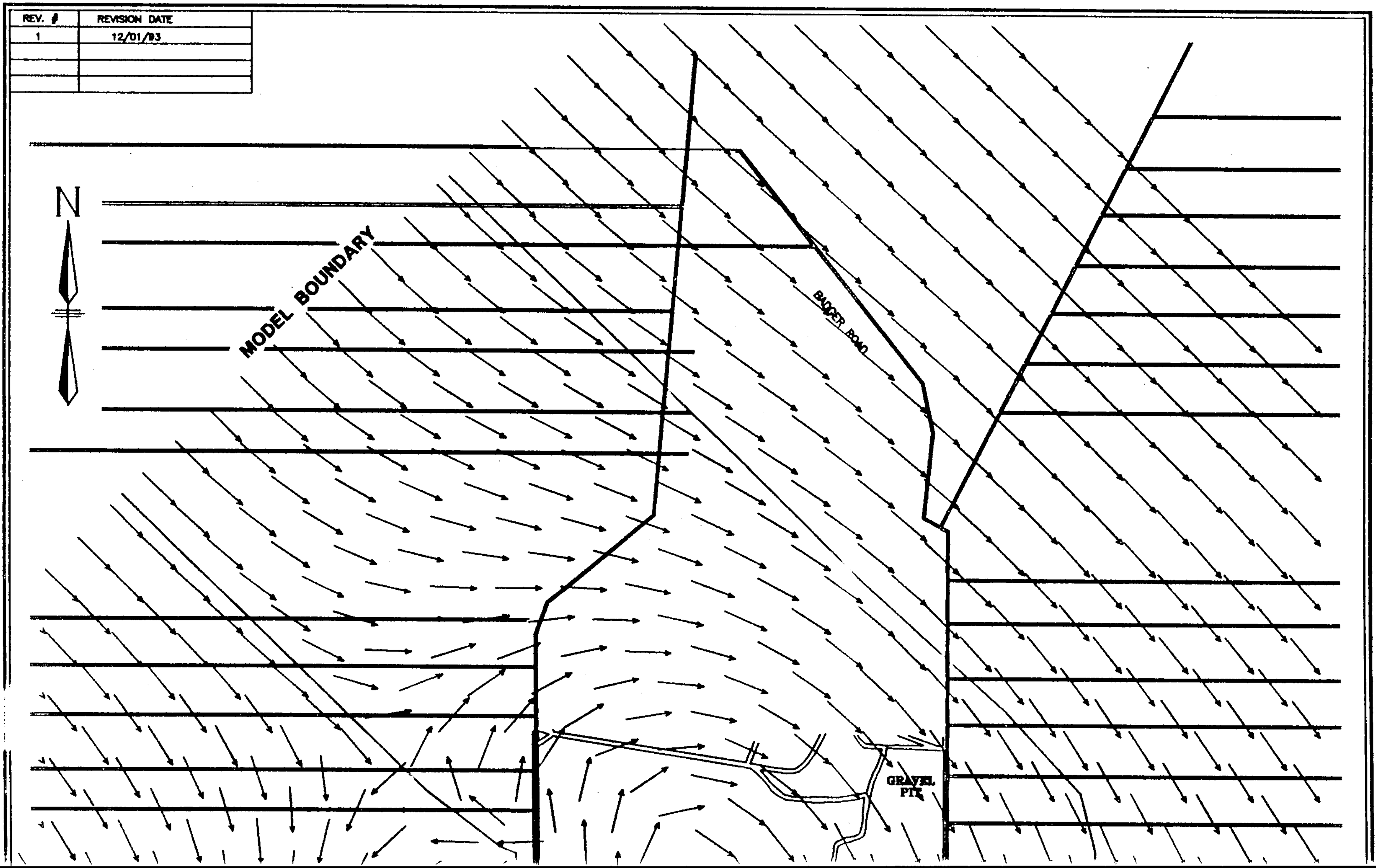
4.2.3.4 Ground Water Extraction. To calculate the rate of ground water extraction and well spacing for the source containment and the aquifer remediation system, the MOC Model was used (see Section 2.3.3, Ground Water Modeling Results). The results of the model indicate that three wells with a total pumping rate of 138 gallons per minute (gpm) for 30 years would be needed to remediate the ground water aquifer to preliminary remedial goals. Figure 4.2.3-2 presents the extraction well locations and the predicted ground water capture zone when the extraction wells are operating. The capture zone extends beyond the known contamination and captures the water discharged to the reinfiltration galley. The capture zone areas were determined visually by observing the computer generated ground water gradient map. Areas where the gradient vector point towards an extraction well were assumed to be captured, while those moving away from the wells were assumed to be outside the capture zone.

Intermediate (15 years) and final (30 years) contour maps are presented in Figures 4.2.3-3 to 4.2.3-6. These figures, along with the capture zone, demonstrate that this alternative will remediate the site and capture the reinfiltrated ground water.

The ground water extraction wells would be 8-inch diameter wells, constructed with a PVC well casing. The ground water would be pumped from each well using individual 100 gpm, 3 hp pumps to allow for the extraction of ground water from specific areas. The same size pump was used for each well to add flexibility to the treatment system.

The ground water pumped from these wells would be collected and pumped via a buried pipeline, to protect against potential freezing problems, into the treatment building. The treatment building would be constructed to protect the processing equipment from adverse weather conditions and to help keep the treatment process at a moderate temperature, which would increase the contaminant removal efficiency.

4.2.3.5 Equalization. The extracted ground water would be pumped to a 7,000-gallon equalization tank, which would provide a 50-minute retention time. The tank is sized to allow mixing and equalization of the three ground water streams, thereby ensuring a relatively uniform feed concentration to the treatment equipment. The equalization tank would also be used as a settling tank to remove any solids from the ground water. Any solids that are collected during the remediation would be drummed and sent to an off-site facility for treatment and ultimate disposal.


N
MODEL BOUNDARY
BADGER ROAD
GRAVEL PIT

REV. #	REVISION DATE
1	12/01/93

1 of 2

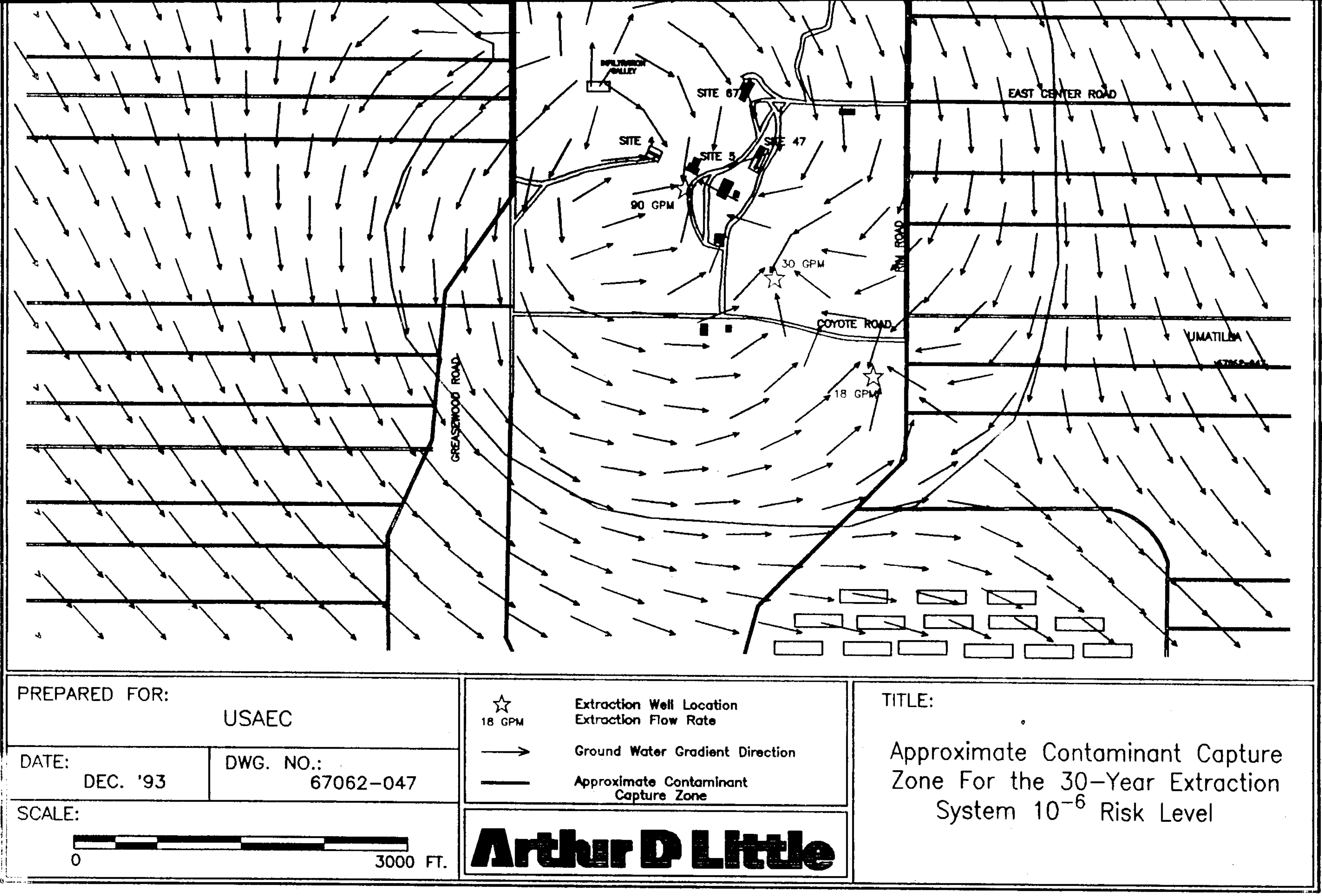

SITE 67
SITE 4
SITE 5
SITE 47
90 GPM
30 GPM
18 GPM
EAST CENTER ROAD
COYOTE ROAD
GREASEWOOD ROAD
UMATILLA
PREPARED FOR:
USAEC
DATE:
DEC. '93
DWG. NO.:
67062-047
SCALE:
0
3000 FT.
18 GPM
Extraction Well Location
Extraction Flow Rate
Ground Water Gradient Direction
Approximate Contaminant Capture Zone
Arthur D Little
TITLE:
Approximate Contaminant Capture Zone For the 30-Year Extraction System 10-6 Risk Level

Figure 4.2.3-2: Approximate Contaminant Capture Zone for the 30-Year Extraction System 10^{-6} Risk Level

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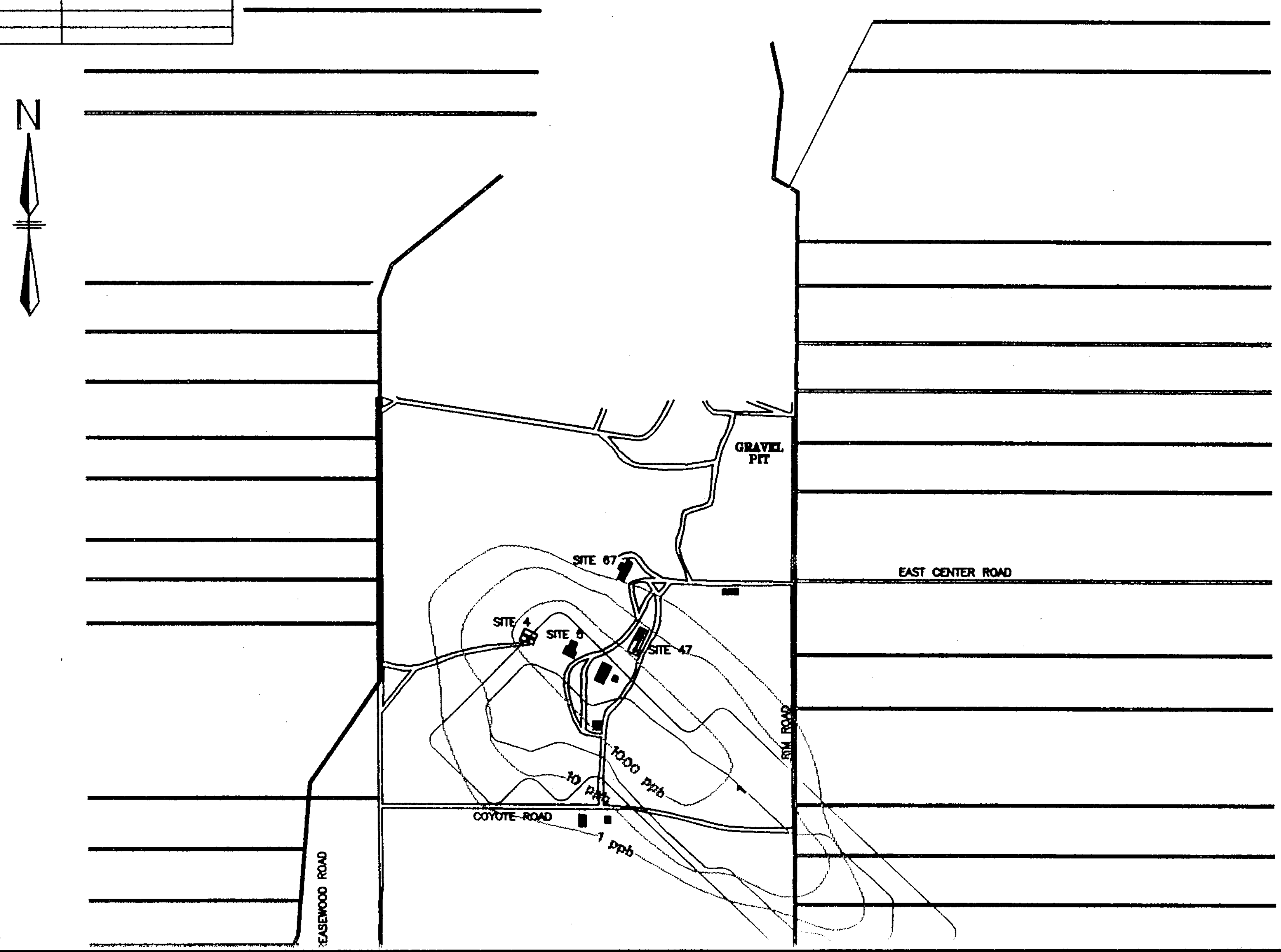
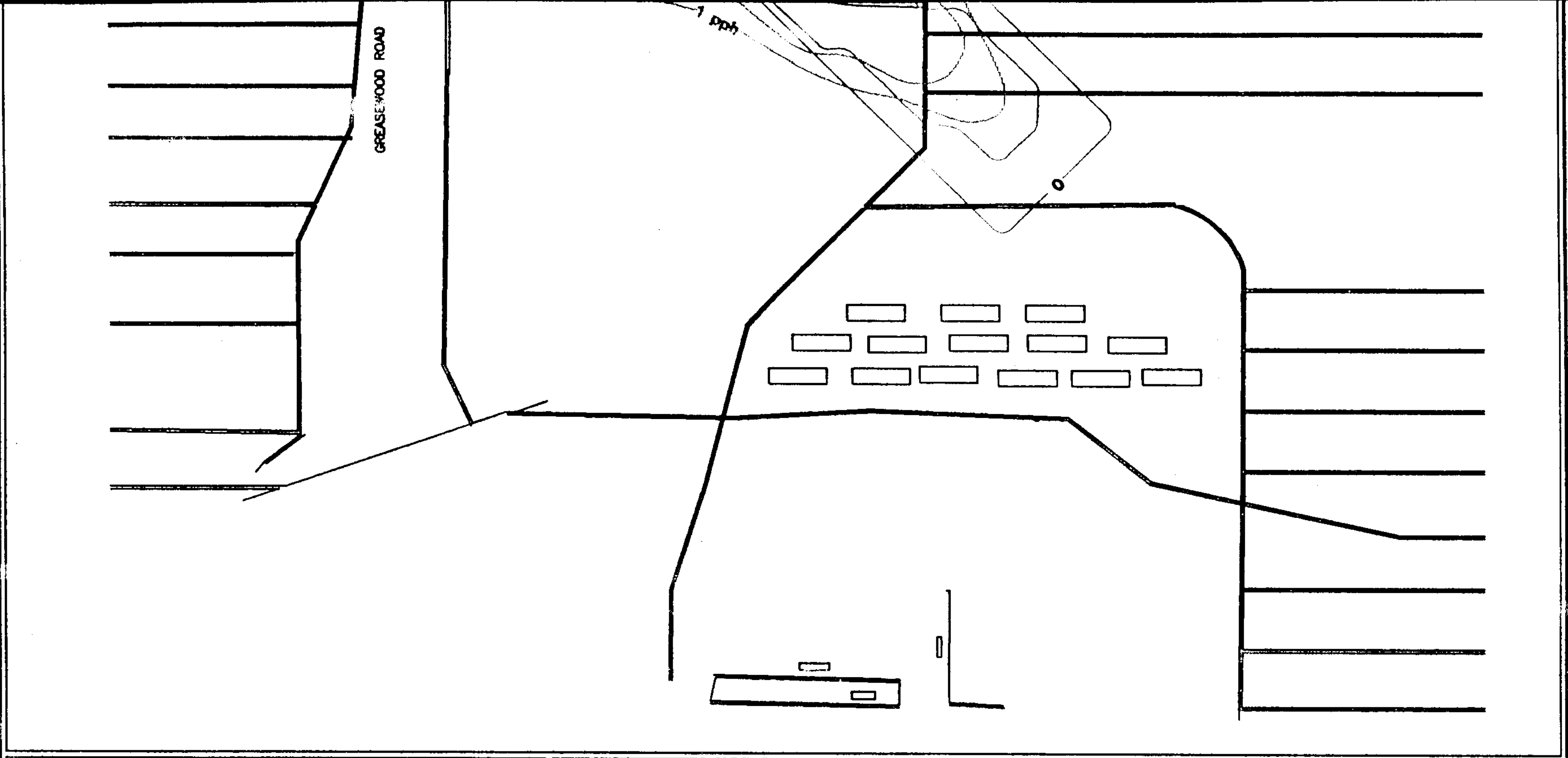

N
GRAVEL PIT
SITE 67
EAST CENTER ROAD
SITE 4
SITE 6
SITE 47
RIM ROAD
1000 ppb
10 ppb
COYOTE ROAD
1 ppb
EASEWOOD ROAD

192



PREPARED FOR:
USAEC

DATE:
DEC. '93

DWG. NO.:
67062–064

SCALE:
0 3000 FT.

—— **Simulated RDX Concentrations after 15 years (ppb)**

┄┄ **Simulated Current RDX Concentrations (ppb)**

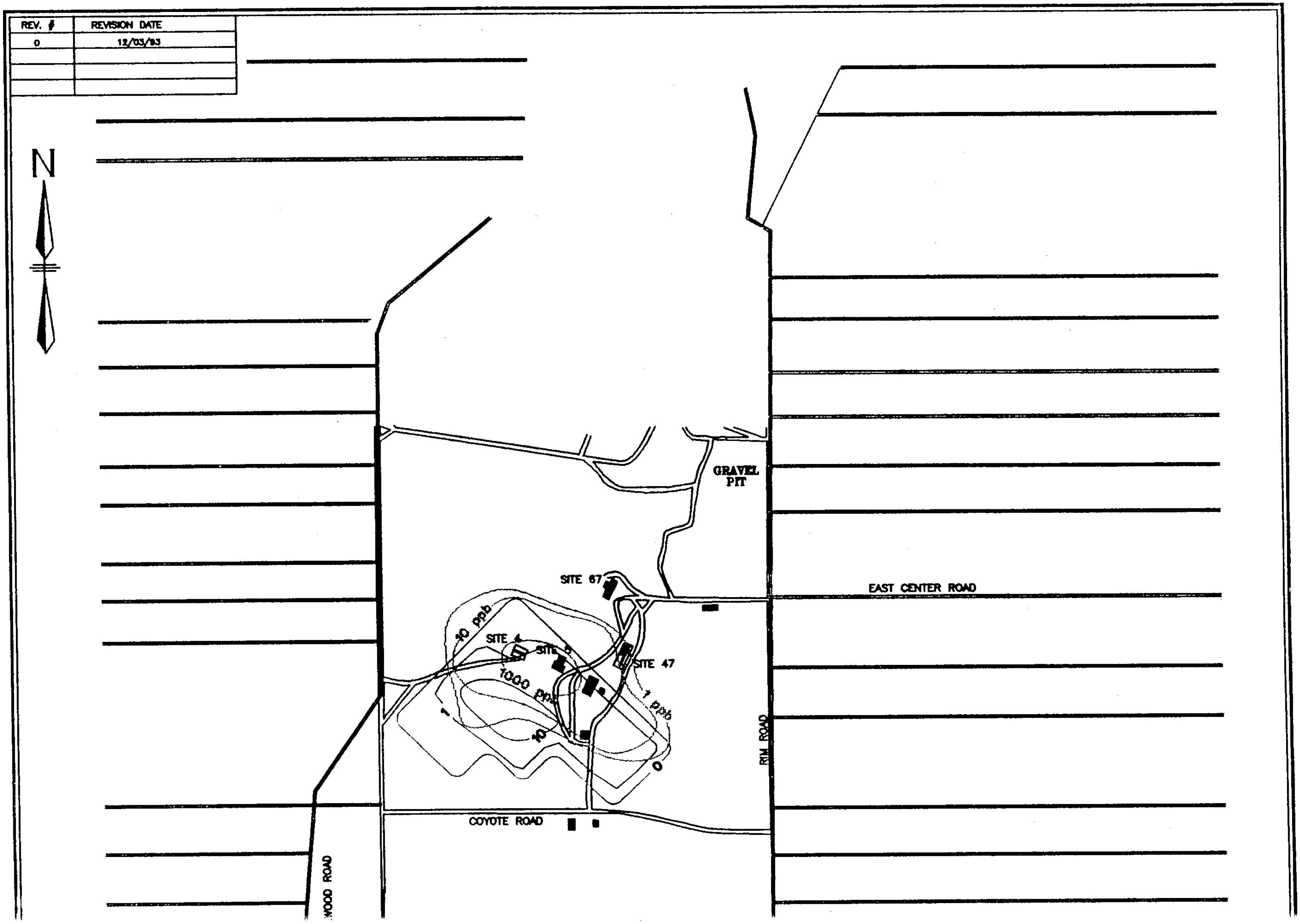
Source: Arthur D. Little, Inc.

Arthur D Little

TITLE:

Simulated RDX Concentrations after 15 years with a Remediation Objective of an Incremental Risk of 1 x 10^{-6} and a Hazard Index of 1

Figure 4.2.3-3: Simulated RDX Concentrations After 15 Years


N
GRAVEL PIT
SITE 67
EAST CENTER ROAD
SITE 4
SITE 6
SITE 47
10 ppb
1000 ppb
1 ppb
1
10
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RIM ROAD
COYOTE ROAD
WOOD ROAD

REV. #	REVISION DATE
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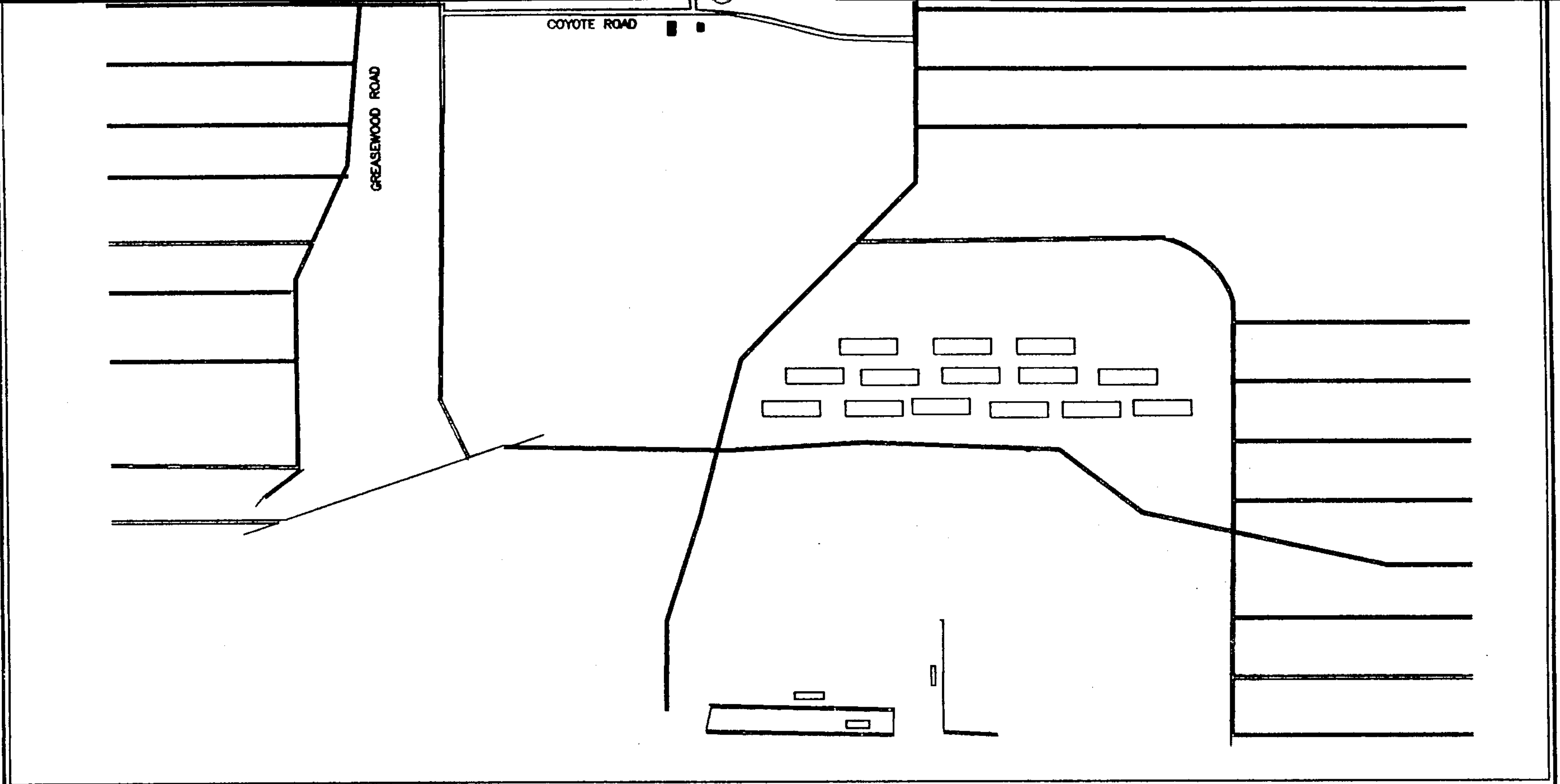
1 of 2



PREPARED FOR:
USAEC

DATE:
DEC. '93

DWG. NO.:
67062–066

SCALE:
0
3000 FT.

Simulated TNT Concentrations after 15 years (ppb)

Simulated Current TNT Concentrations (ppb)

Source: Arthur D. Little, Inc.

Arthur D Little

TITLE:

Simulated TNT Concentrations after 15 years with a Remediation Objective of an Incremental Risk of 1 x 10^{-6} and a Hazard Index of 1

Figure 4.2.3-4: Simulated TNT Concentrations After 15 Years

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REV. #	REVISION DATE
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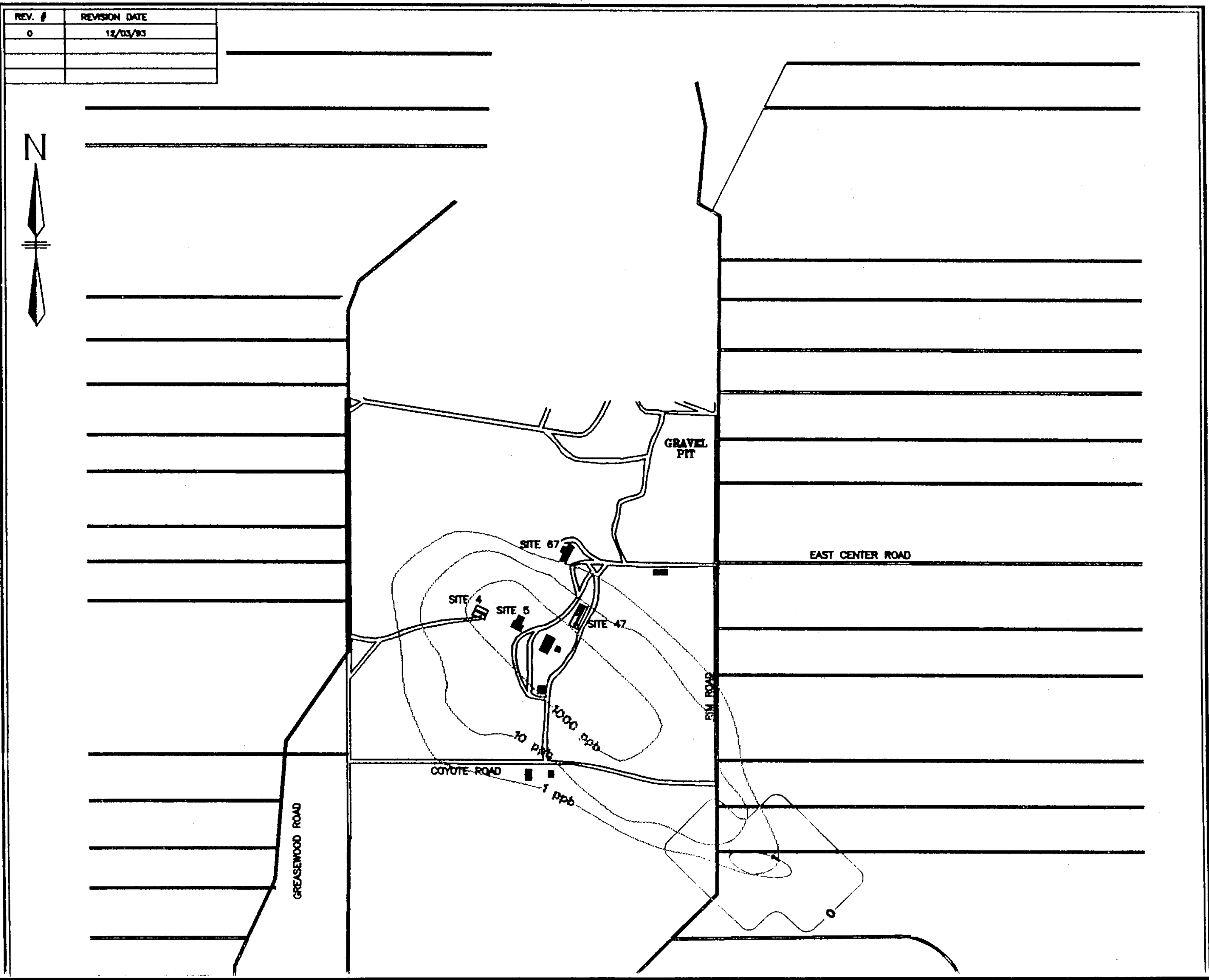
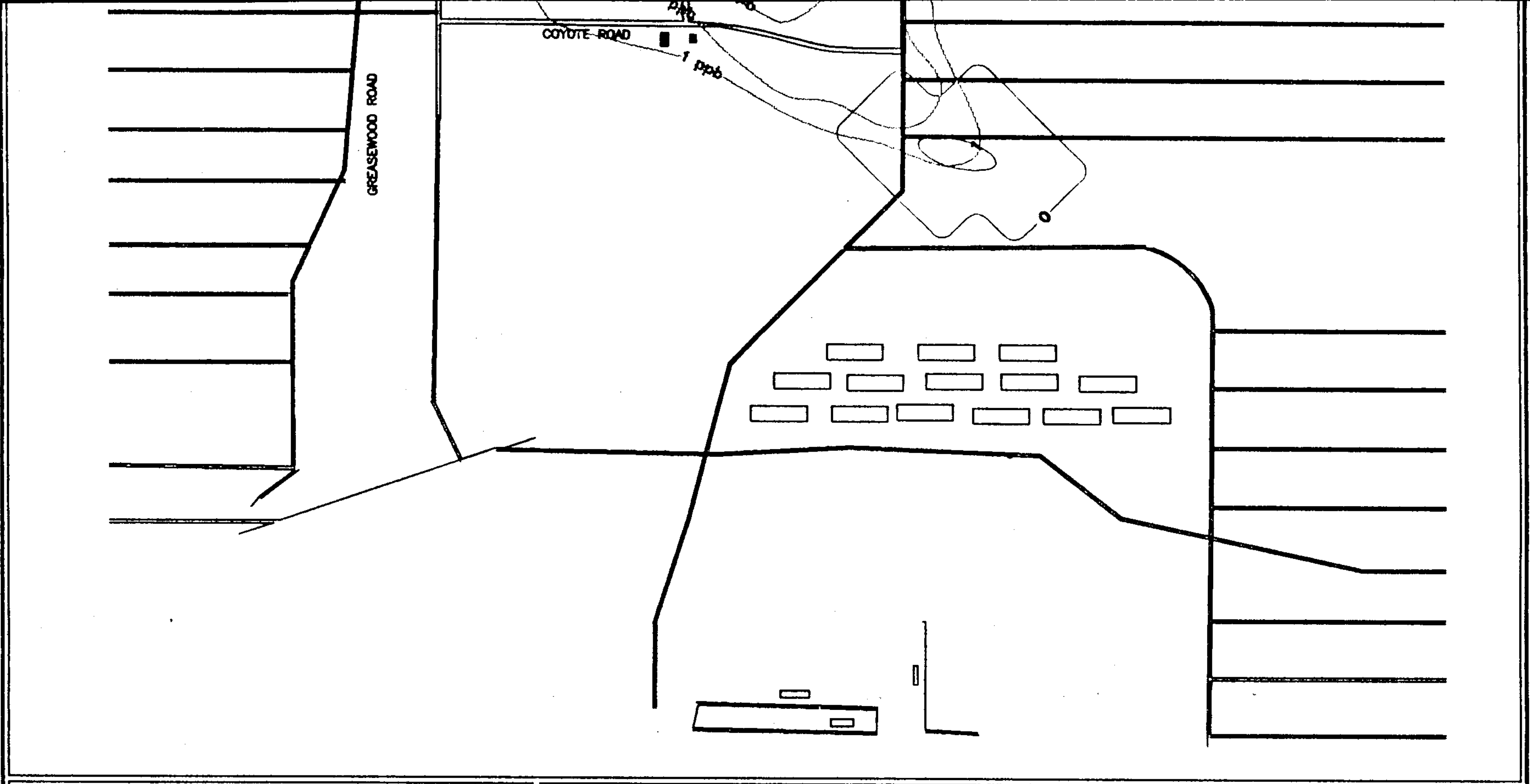

N
GRAVEL PIT
EAST CENTER ROAD
SITE 67
SITE 4
SITE 5
SITE 47
RIM ROAD
1000 ppb
10 ppb
1 ppb
COYOTE ROAD
GREASEWOOD ROAD
0



PREPARED FOR:
USAEC

DATE:
DEC. '93

DWG. NO.:
67062-063

SCALE:
0 3000 FT.

——— Simulated RDX Concentrations after 30 years (ppb)

——— Simulated Current RDX Concentrations (ppb)

Source: Arthur D. Little, Inc.

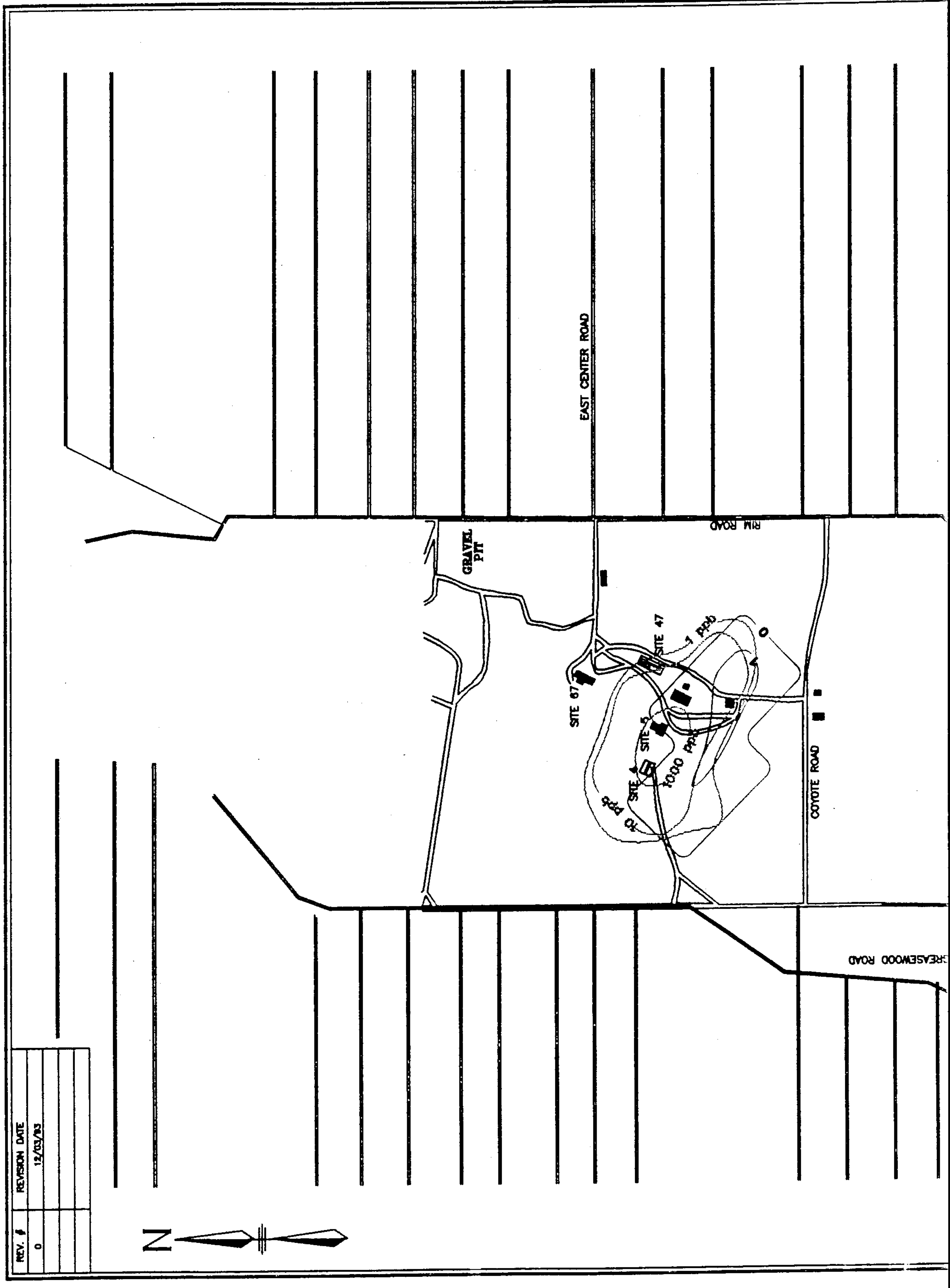
Arthur D Little

TITLE:

Simulated RDX Concentrations after 30 years with a Remediation Objective of an Incremental Risk of 1 x 10^{-6} and a Hazard Index of 1

Figure 4.2.3-5: Simulated RDX Concentrations After 30 Years

2 of 2


EAST CENTER ROAD
RIM ROAD
GRAVEL PIT
SITE 47
SITE 67
SITE 5
SITE 4
1 ppb
0
1000 ppb
10 ppb
COYOTE ROAD
REASEWOOD ROAD
N

REV. #	REVISION DATE
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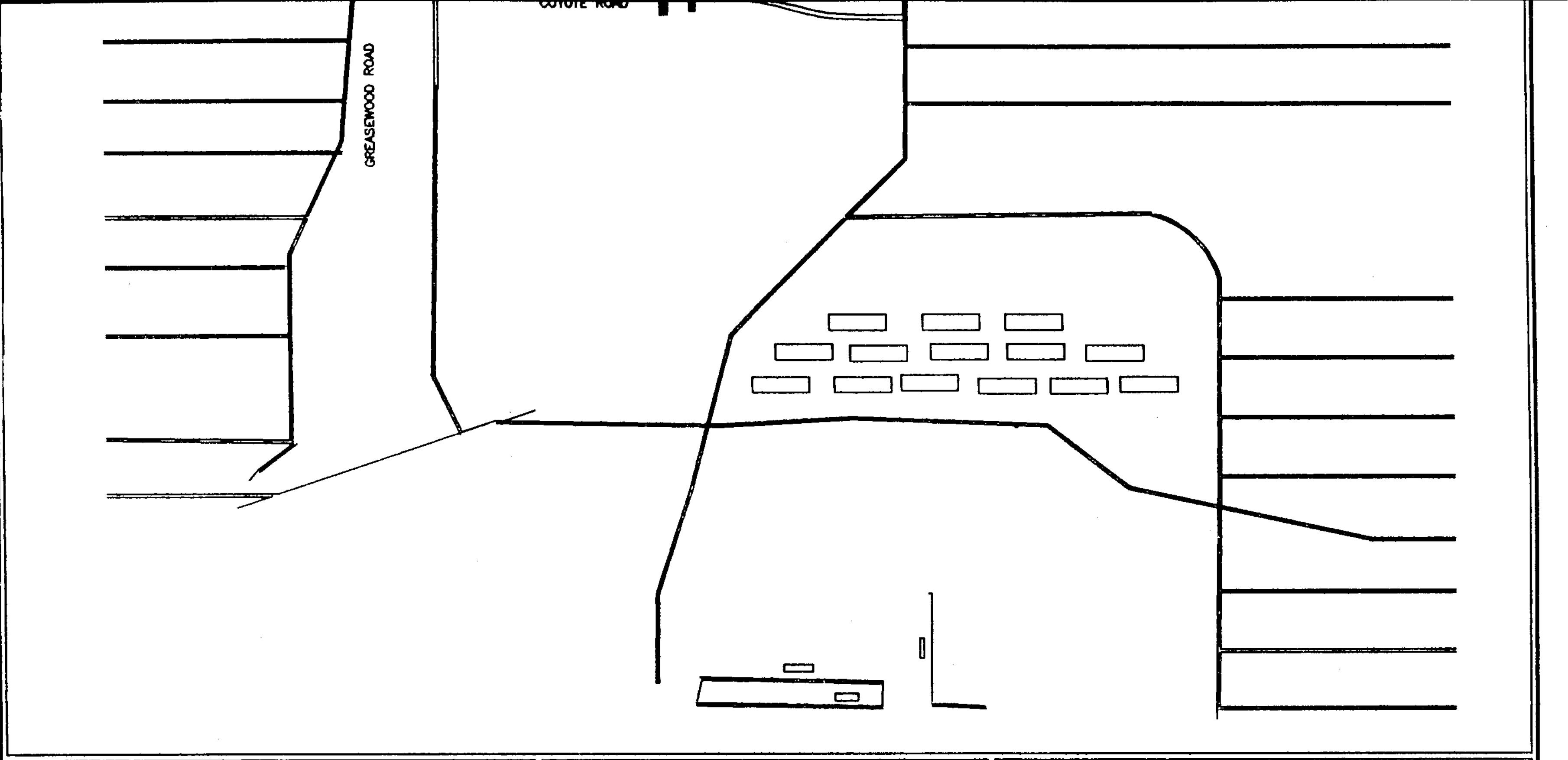


PREPARED FOR: USAEC

DATE: DEC. '93

DWG. NO.: 67062-065

SCALE: 0 3000 FT.

—— **Simulated TNT Concentrations after 30 years (ppb)**

---- **Simulated Current TNT Concentrations (ppb)**

Source: Arthur D. Little, Inc.

Arthur D Little

TITLE:

Simulated TNT Concentrations after 30 years with a Remediation Objective of an Incremental Risk of 1 x 10^{-6} and a Hazard Index of 1

Figure 4.2.3-6: Simulated TNT Concentrations After 30 Years

4.2.3.6 Ultraviolet/Oxidation.

4.2.3.6.1 Metal Precipitation. The ground water would be pumped from the equalization tank to the metals precipitation unit for treatment to minimize the potential for fouling the UV lights; this system should also reduce any elevated metal concentrations to below naturally occurring background levels. The metals precipitation process would include an oxidation system, pH adjustment vessel, a stirred reactor, a clarifier to remove precipitated metals, and a multimedia filter to remove any remaining suspended solids. The operating parameters and the volume of material required on a daily basis for a typical metals precipitation system are shown below:

Parameter	**Operating Condition**
$KMnO_4$ Dose	40 mg/L (29 kg/day)
Operating pH	11.0 units
NaOH Dose	400 mg/L (294 kg/day 50% NaOH)
Anionic Polymer Dose	3 mg/L (2.2 kg/day)
H_2SO_4 Dose	490 mg/L (360 kg/day 50% H_2SO_4)
Sludge Production	0.51 tons/day (@ 30% solids)

4.2.3.6.2 UV/ Oxidation. After the metal precipitation system, the pH of the ground water will be adjusted to a value of 6 to 7 and pumped to the UV/oxidation system. The UV/oxidation system will be operated with ozone (O_3) as the oxidant, based upon the results of the Milan Army Ammunition treatability study (ICF Kaiser Engineers, 1993) that indicated that hydrogen peroxide is not an effective oxidant for a similar waste stream. For design and costing purposes only, an O_3 system was selected. However, in the remedial design for the ground water at the Explosive Washout Lagoons, the choice of oxidant(s) to use should be based on additional data to be provided by Dames & Moore as a result of the conduct of the Treatability Study currently being performed at UMDA.

The O_3 would be added to the extracted ground water stream at a rate of 2 mg/L/min as it passed through the reactor system. The reactors would provide a minimum UV light intensity of 0.07 kw/liter of ground water with a residence time of 45 minutes, and would be modular in design. The modular design would allow banks of lights to be shut down as the contaminant loading decreased over time, thus ensuring an economically efficient treatment system for the lifetime of the project. A 90% destruction of the total explosives concentration should be achieved using the operating parameters described above. This overall destruction value is limited by the fact that 2,4,6-TNT is oxidized to 1,3,5-TNB, which then takes a comparable amount of time to be oxidized to harmless constituents. The other compounds present in the contaminated plume have been shown to degrade within this 45-minute retention time.

The UV/oxidation system would have a cleaning mechanism for the quartz tubes to reduce the fouling of the tubes, which would otherwise reduce the UV emittance. After leaving the UV reactor, the treated ground water would require final polishing by a liquid phase granular activated carbon (GAC) system to remove residual TNB produced by the oxidation of the TNT. It would not be economical to operate the full-sized UV/oxidation system for TNB removal, as this would require an additional 30 minutes of treatment time, thereby significantly increasing operating expenses. The GAC system will also act as a remedial backup in the event of a UV/oxidation system malfunction.

4.2.3.6.3 GAC Polishing. The GAC polishing unit would consist of two parallel treatment trains consisting of 2,000-pound carbon beds contained in tanks sized to allow for adequate absorbent time. The carbon beds would not be operated until saturation, but rather only until an average 0.07 lb contaminant per lb GAC loading was achieved. This ceiling on loading is to ensure that the adsorbed contaminant/GAC matrix does not approach its explosive limit and, therefore, not be considered a RCRA characteristic waste. When test results indicated that the carbon bed was spent, the polishing system would be switched over to the standby bed. Each carbon bed is expected to last approximately 160 days based upon the design flowrate and expected UV/oxidation system effluent concentration.

To change the spent carbon, untreated water from the equalization vessel would be used to slurry the column into a hopper. The GAC would be allowed to gravity drain for approximately 24 hours, and would then be screw-fed from the hopper into drums. The water drained from the hopper would be collected and recirculated back to the equalization vessel for treatment.

The drums containing the spent, but non-saturated, carbon would be shipped off site for thermal treatment (e.g., incineration, cement kiln, regeneration). Incineration was selected for costing purposes in the FS because it is the most common disposal method for explosive laden GAC at explosive manufacturing plants (Arthur D. Little, 1993). Several commercial incineration facilities were determined to be capable of handling explosive-laden GAC in bulk or drum. These commercial facilities included: the Chemical Waste Management incinerators in Port Arthur, Texas and Chicago, Illinois, the Rollins Environmental Services Incinerators in Deer Park, Texas and Lake Charles, Louisiana, as well as the ENSCO incinerator in El Dorado, Arkansas, which is a Defense Logistics Agency-approved site. GAC incineration costs included in this section were based on the average per drum cost obtained from personnel at these facilities. To minimize costs and risks associated with transportation, it would be desirable to use an incineration facility close to the site; however, the closest incineration facility found to be willing and capable of treating the spent GAC was located in Texas. Additional facilities should be investigated during the Remedial Design.

4.2.3.7 Reinfiltration. After the ground water has been treated and meets all preliminary remediation goals, the water will initially be pumped to the explosive washout lagoons, where it will be allowed to reinfiltrate into the soils under the lagoons. Reinfiltration of the treated ground water into the lagoons will help flush the remaining soil contamination into the ground water table, where it will be collected downgradient in the extraction wells. The flushing of the soil contamination will take approximately eight months based upon the model presented in Section 2.4. The objective of the flushing of the soils beneath the lagoons is to further limit the potential for the explosives to be transported to the ground water and to provide additional explosive recovery. The ability to remove the explosives through ground water flushing is uncertain and will require close monitoring during the remedial action to ensure that the contaminants are not being spread into currently uncontaminated regions. If the contaminants are found to be spreading into uncontaminated regions, then the reinfiltration to the lagoons will be stopped until further options can be evaluated. In addition, consideration should be given to running bench-scale flushing studies with actual washout lagoon soil to further model the transport of the contaminants in the actual remediation.

The infiltration of the ground water into the lagoons will be completed by laying perforated PVC piping in 2 feet of crushed stone at the bottom of the excavated lagoons. A liner will then be placed over the stone and the treated soil from the composting system will be placed on top of the liner. The actual design of this distribution system needs to be investigated further during the Remedial Design to calculate a percolation rate and ensure that the ground water is evenly distributed over the lagoons and all areas are flushed.

After approximately eight months, the reinfiltration of the treated ground water will be directed to an infiltration galley 400 to 800 feet upgradient of the lagoons. The galley will have five rows, each 112 feet long, and a total surface area of 2,170 square feet. The reinfiltration of the ground water will be changed to minimize the concern that the discharge of the ground water to the washout lagoons over a long period of time may result in the spreading of the contamination and an increase in the length of time to clean up the aquifer.

The preliminary design of the infiltration galley is based on a formula developed by the U.S. Department of the Interior, Bureau of Reclamation. This formula develops an infiltration rate based on the saturated vertical hydraulic conductivity (K_v) which is a function of both the soil porosity and the percolation rate of the soil. The percolation rate is not known for the area near the washout lagoons; therefore, based on soil boring data presented in the RI, a percolation rate of 2 minutes per inch and an effective porosity of 0.2 were estimated. Actual percolation tests will need to be conducted during the Remedial Design to verify this estimate.

There are a number of different types of systems that could be used to provide these infiltration areas. These include such systems as leaching pits, fields, trenches, or galleys. For the purpose of this FS, we have selected the use of leaching galleys; however, during the Remedial Design, one of the other types of systems may be selected. A leaching galley is a 4 by 4 by 4 foot concrete box with two open ends and perforated sides and bottom. These boxes are linked together into rows that provide both infiltration area and some level of storage if there are fluctuations in the flow rate to the leaching galleys. In sizing the leaching galleys, we have taken into account the bottom area of the leaching galleys even though there will be some infiltration through the side walls. This provides some extra capacity for the system if the percolation rate is lower than assumed or if additional pumping is required to meet the cleanup levels.

4.2.3.8 Capital Cost. The capital cost for the UV/oxidation system is approximately $2.2 million, as is presented in Table 4.2.3-1. The capital cost of this alternative is strongly dependent on the cost of the UV/oxidation system which is approximately 50% of the overall capital cost. The cost of the UV/oxidation system would be increased if the volume of water to be treated increased or the retention time to reach the preliminary remedial goals increased. If the water volume to the UV system was increased or the retention time was increased by 50% the capital cost would be increased from $2.2 million to $2.9 million. The capital cost would also be increased if the number of extraction wells needed to be increased to ensure that the capture zone was maintained; if the number of wells was doubled the total capital cost would only be increased by approximately $175,000.

4.2.3.9 Operating Cost. The annual operating cost for the UV/oxidation system is approximately $0.79 million, as is presented in Table 4.2.3-2. Using the annual operating cost, the NPV was calculated for the 30 year scenario, using a 5% and a 10% interest rate.

		5% Interest Rate		10% Interest Rate	
Time Frame	**Annual Cost**	**Discount Factor**	**NPV**	**Discount Factor**	**NPV**
1-30 years	$0.79M	15.8	$12.5M	9.9	$7.8M

The operating cost for this alternative is strongly dependent on the electrical cost for the operation of the UV/oxidation system. The electrical cost would increase if the size of the UV/oxidation system was increased. A 50% increase in the size of the UV/oxidation system would increase the electrical costs from $366,000 to $450,000, and the 5% NPV would increase from $12.5 million to $13.8 million.

4.2.3.10 NCP Evaluation Criteria. The degree to which UV/oxidation of the contaminated ground water meets the NCP evaluation criteria is discussed below.

Table 4.2.3-1: Capital Cost for Ultraviolet/Oxidation – Alternative 3A

Item No.	Item	Units	Unit Cost (1993 $)	# of Units	Total Cost (1993 $)
100	**Extraction**				
101	GW Wells - 8 inch, 155 feet	Well	30,000	3	90,000
102	GW Well Pumps - 100 gpm, 3 hp	Pump	1,550	3	4,650
103	GW Buried Pipeline	Pipeline/500 ft	4,250	6	25,500
200	**Equalization**				
201	Equalization/Settling - 7,000 gal	Tank	19,000	1	19,000
202	Feed Pump - 200 gpm, 5 hp	Pump	2,200	2	4,400
300	**Metal Precipitation**	System	160,000	1	160,000
301	pH Control System				
302	Oxidant Addition Pump				
303	Treatment Tank with Mixer				
304	Polymer Feed System				
305	Clarification System				
306	Sludge Thickening System				
307	Filter Press				
308	Multi-Media Filter				
400	**UV/Oxidation**	System	900,000	1	900,000
401	UV Reactor				
402	UV Feed Pump				
403	Ozone Generation and Destruction				
500	**Granular Activated Carbon**				
501	GAC Tank - 2000 gal	Tank	4,250	2	8,500
502	GAC Adsorber - 2000 lb	Bed	4,500	2	9,000
503	Discharge Pump - 200 gpm, 7 hp	Pump	2,300	2	4,600
600	**Reinfiltration Galley**				
601	Excavation	C.Y.	2	909	1,818
602	Crushed Stone	C.Y.	19	302	5,738
603	Backfill	C.Y.	2	90	180
604	Infiltration Galley	Galley	200	140	28,000
700	**Lagoon Lining**				
701	HDPE Liner	Lagoon	3,000	2	6,000
702	Crushed Stone	C.Y.	19	520	9,880
Equipment Subtotal					$1,277,266
Remedial Design / Planning		10 % of Purchased Equipment Cost			127,727
Plumbing		10 % of Purchased Equipment Cost			127,727
Electrical		10 % of Purchased Equipment Cost			127,727
Instrumentation and Controls		10 % of Purchased Equipment Cost			127,727
Construction and Installation		30 % of Purchased Equipment Cost			383,180
Treatment System Building		sq feet	27	1,200	32,400
Installation Subtotal					$926,486
Total Capital Cost					$2,203,752

Source: Arthur D. Little, Inc.

Table 4.2.3-2: Annual Operating Cost for Ultraviolet/Oxidation - Alternative 3A

Item	Units	Units/ Year	Unit Cost (1993 Dollars)	Annual Cost (1993 Dollars)
Variable Cost				
Monitoring				
Sample Collection	hours	640	30	19,200
Supervision	hours	32	50	1,600
Sample Analysis	samples	152	150	22,800
Data Review and Reporting	hours	32	65	2,080
Five -Year Review (a)	hours	50	80	4,000
Metals Precipitation (b)	1000 gal (c)	70,956	0.4	28,382
Electrical (d)	kw/yr	6,100,000	0.06	366,000
Ozone	1000 gal (c)	70,956	0.25	17,739
Granular Activated Carbon				
GAC Bed - 2000 lbs	ton	2.3	4500	10,350
GAC Incineration (e)				
Polyethylene Lined Drums	drum	13.7	25	343
Shipping	drum	13.7	125	1,713
Treatment/Disposal	drum	13.7	420	5,754
Disposal (f)	ton	185	300	55,500
Operational Monitoring	samples	100	150	15,000
Labor				
Operator (g)	hours	2,500	30	75,000
Supervisor (h)	hours	200	50	10,000
Variable Cost Subtotal				$635,460
Fixed Cost				
Maintenance				
Labor and Materials	7% of Capital Investment			154,260
Fixed Cost Subtotal				$154,260
Total Annual Operating Cost				$789,720

Notes:
(a) – The cost for the Five-Year Review has been divided evenly over five years
(b) – Operating cost for metal precipitation includes power and chemicals
(c) - Untreated ground water
(d) – Electrical includes power for pumps, UV lights, and misc. electrical for heating building, lighting, etc
(e) - Assumes 335 pounds of dewatered GAC/55 gallon drum
(f) – Includes disposal of any solids or from equilization tank and disposal of metal hydroxide sludge from metal precipitation
(g) – Two operators on-site 3.0 days/week
(h) – One supervisor 4 hours/week to review operation of process

Source: Arthur D. Little, Inc.

Overall Protection of Human Health and the Environment

This alternative would return the ground water to its potential beneficial use within 30 years. Upon achieving the remedial action objectives, the total hazard index for the ingestion of ground water for all compounds, at reasonable maximum exposure, would be reduced from 60 to 2. The total incremental cancer risk for the ingestion of ground water for all compounds at reasonable maximum exposure would be reduced from $2x10^{-3}$ to $1.3x10^{-5}$ (see Section 2.1, Remedial Action Objectives).

The alternative would also provide treatment of the contamination on site, except for small volumes of residuals such as the metal hydroxide sludge for the precipitation system and the spent carbon from the polishing system. The alternative would not pose a short term risk to human health or the environment and would maximize the amount of water that was returned to the aquifer.

Compliance with ARARs

The alternative would meet the preliminary remediation goals in 30 years. The alternative would meet all action-specific ARARs, including:

- No state and federal safe drinking water regulations exist for the contaminants of concern; therefore, the extracted ground water will be treated to ensure that each compound meets a hazard index equal to or less than 1 and an excess cancer risk of greater than 10^{-6}, or the compounds analytical detection limit prior to its return to the aquifer.

- State surface water discharge or underground injection regulations on the disposal of the treated ground water.

- All RCRA requirements will be met in regard to the transport and disposal of the residuals from the treatment process. The explosive concentration in the spent carbon will be equal to or less than 7%, which is well below the explosive limit of 10% (Arthur D. Little, 1987). TCLP analysis of the spent GAC would have to be performed to ensure that the DNT concentration is below the RCRA limit.

Long-Term Effectiveness

The residual risk that would remain on site due to contamination in the ground water would be reduced to a hazard index of 2 and a carcinogenic risk of $1.3x10^{-5}$ in 30 years. Without active contamination treatment, the risk reduction would not be reached for an estimated 5,000 years.

Treatment residuals that are generated during the remediation of the ground water would be disposed of in a manner to eliminate unacceptable risks. The metal hydroxide sludges from the metal precipitation unit would be disposed of in a solid waste landfill, depending on the results of a TCLP and the contaminants adsorbed on the spent GAC would be destroyed by off-site incineration or by another type of thermal treatment (regeneration or cement kiln). Any solids removed from the equalization tank would be shipped off-site for treatment and disposal.

The alternative would be operated until the ground water met the preliminary remedial goals, and the contaminants would be either destroyed on site in the UV/oxidation system or off site when the carbon is incinerated or by another type of thermal treatment (regeneration or cement kiln). Therefore, no long-term controls would be necessary. All the technologies that would be used in this alternative are considered reliable.

This alternative would require five-year reviews to evaluate whether the alternative is protective of public health and the environment. The five-year reviews would be initiated five years after the start of the remedial action and would continue until no contaminants remain at the site above levels that allow for unrestricted use and unlimited exposure.

Reduction of Toxicity, Mobility, or Volume Through Treatment

The UV/oxidation system would irreversibly destroy the contaminants directly by oxidizing the contaminants. Any remaining contaminants would be removed by the GAC system. The UV/oxidation system would remove approximately 90% of the contamination from the ground water stream (ICF Kaiser Engineers, 1993). The remaining contaminants would be treated using the GAC system. The contamination adsorbed on the GAC will be irreversibly destroyed by off-site incineration of the carbon or by another type of thermal treatment (regeneration or cement kiln). This treatment system will reduce the volume, toxicity, and mobility of the contaminants.

The metal precipitation system will generate metal hydroxide sludges at a rate of approximately 186 tons/year. These sludges will be disposed of off site as a solid waste depending on the results of a TCLP analysis. In addition to the sludges, an estimated 100 pounds of sediment will be collected each year in the equalization tank that will be analyzed and disposed of off site if found to be free of contamination.

Short-Term Effectiveness

The operation of the UV/oxidation system is not expected to increase the risk to the community or the environment because the contaminants will be irreversibly destroyed or adsorbed on the GAC and incinerated. The risks to the workers and the environment from using the acids, bases, and ozone would be minimized through the use of engineering controls and personal protective equipment.

The alternative would meet the remedial action objectives within 30 years. If no active remediation alternative is implemented at the site, the ground water will not meet the remedial action objectives for an estimated 5,000 years.

Implementation

The construction and operation of the UV/oxidation system can be easily implemented and the system is technically capable of treating the contaminants in the ground water. The capacity of the UV/oxidation system can be increased if additional ground water needs to be treated or the concentration of contamination is greater than expected.

There is some uncertainty surrounding the reinfiltration of treated ground water into the lagoons to flush the remaining contaminants from the soils. Because there is the potential for the reinfiltration spreading the contamination, the ground water in the vicinity of the lagoons will have to be monitored to ensure that reinfiltration is not adversely affecting the ability to remediate the ground water. If there is a concern, then the ground water will be switched to the reinfiltration galleys upgradient.

No special equipment, materials, or technical specialists would be required for the implementation of the UV/oxidation system. Vendors are also currently available for the supply and incineration of the GAC.

State and local coordination would be required for the implementation of legal restrictions on the use of ground water at the site and the discharge of treated ground water to the environment.

Cost

The capital and operating costs are presented in Section 4.2.3.8 and Section 4.2.3.9, respectively.

4.2.4 Alternative 3B - UV/ Oxidation (10 Years, Remediated to Preliminary Remedial Goals)

In this alternative, the ground water will be extracted from a series of three wells over a 10-year period to remediate the ground water to preliminary remedial goals as shown in Section 2.1.5, Preliminary Remediation Goals for Ground Water (2.1 µg/L for RDX and 2.8 µg/L for TNT). The ground water will be treated by hydroxide precipitation to remove the background metals from the contaminated ground water and then treated by UV/oxidation to destroy the explosives (see Figure 4.2.3-1). Since it is not economically feasible to achieve complete contaminant destruction with UV/oxidation treatment, granular activated carbon (GAC) with off-site incineration, or another thermal treatment (e.g., regeneration, cement kiln), of the spent carbon will be included as a polishing step to UV/oxidation.

After the ground water has been treated and meets all preliminary remedial goals, 200 gpm will initially be pumped to the explosive washout lagoons, where it will be allowed to reinfiltrate into the soils under the lagoons. The additional 130 gpm will be pumped to the reinfiltration galleys. Reinfiltration of the treated ground water into the lagoons will flush the remaining soil contamination into the ground water table where it will be collected downgradient in the extraction wells. After approximately six months the reinfiltration of the treated ground water will be moved to infiltration galleys 400 to 800 feet upgradient of the lagoons.

In addition, this alternative will require ground water monitoring, five-year reviews, and institutional controls, which will continue until the contamination has been remediated to the detection limits stated above.

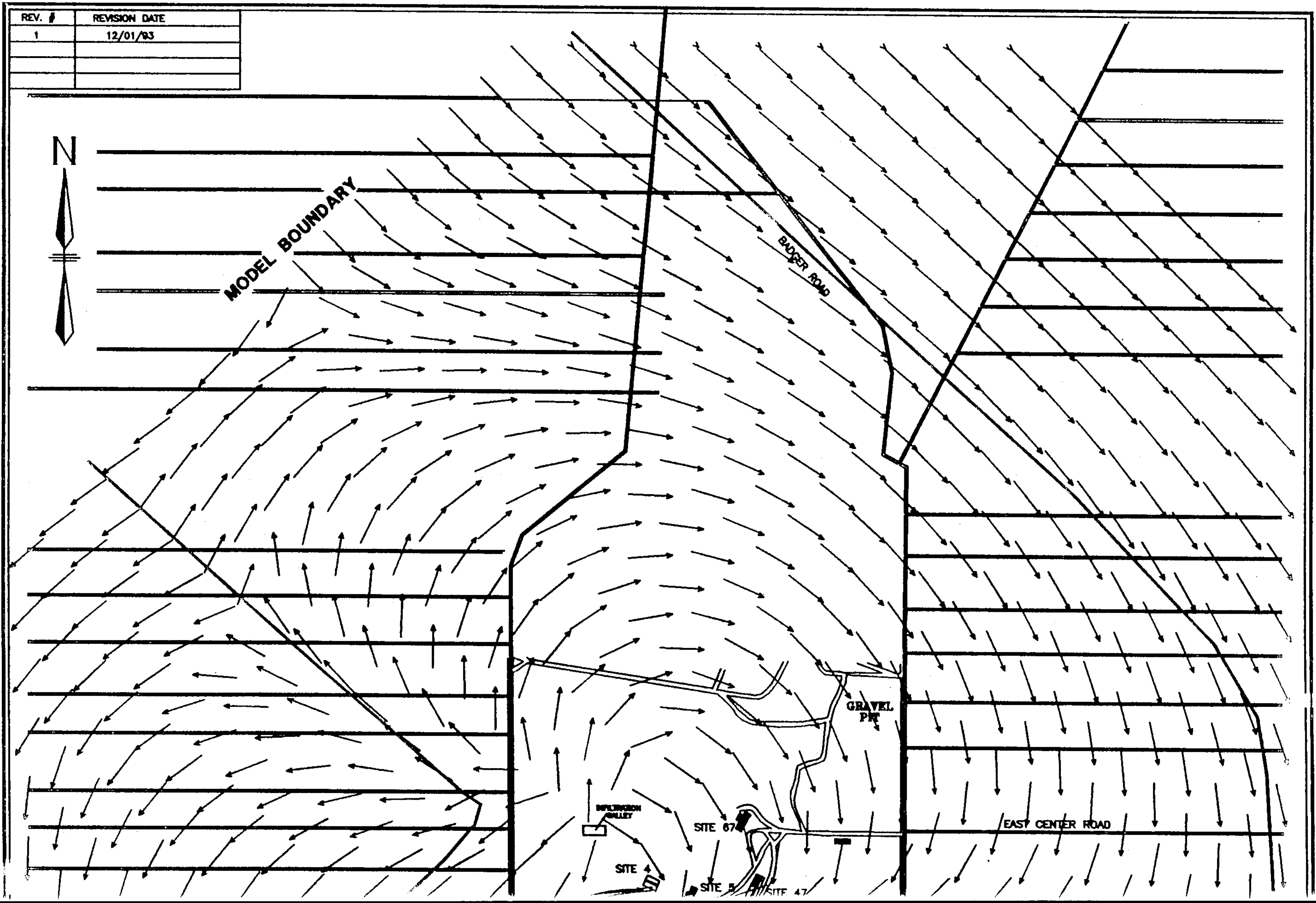
4.2.4.1 Institutional Controls. While the ground water is being remediated, institutional controls will be needed to restrict access to the contaminated aquifer, the contaminated ground water remediation equipment and the interconnecting piping. The level of institutional controls is similar to that previously discussed in Section 4.2.2, Alternative 2, and will not be repeated here.

4.2.4.2 Monitoring. The monitoring program would sample the existing monitoring wells and is identical to the program presented in Section 4.2.2.2, Monitoring, for the Institutional Control Alternative.

4.2.4.3 Five-Year Reviews. In addition to the monitoring of the ground water and the institutional controls, this alternative would also require five-year reviews intended to evaluate whether the alternative remains protective of public health and the environment. The five-year reviews would be initiated five years after the start of the remedial action and continue until no contaminants remain at the site above levels that allow for unrestricted use and unlimited exposure. These reviews would be identical to the reviews described for the No Action alternative (see the introduction to Section 4.2, Individual Analysis of Alternatives).

4.2.4.4 Ground Water Extraction. The extraction method for this ground water alternative would be identical to the extraction method described for Alternative 3A (see Section 4.2.3.4, Ground Water Extraction), except that the total pumping rate would be 333 gpm. Figure 4.2.4-1 presents the extraction well locations and the predicted ground water capture zone when the extraction wells are operating. Intermediate (15 years) and final (10 years) contour maps are presented in Figures 4.2.4-2 to 4.2.4-5. These figures along with the capture zone, demonstrate that this alternative will remediate the site and capture the reinfiltrated ground water.

4.2.4.5 Equalization. The equalization method for this ground water alternative would be identical to the equalization method described for Alternative 3A (see Section 4.2.3.5, Equalization), except that extracted ground water would be pumped to a 18,000-gallon equalization tank that would provide an approximately 50-minute retention time.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GRAVEL PIT
INFILTRATION GALLERY
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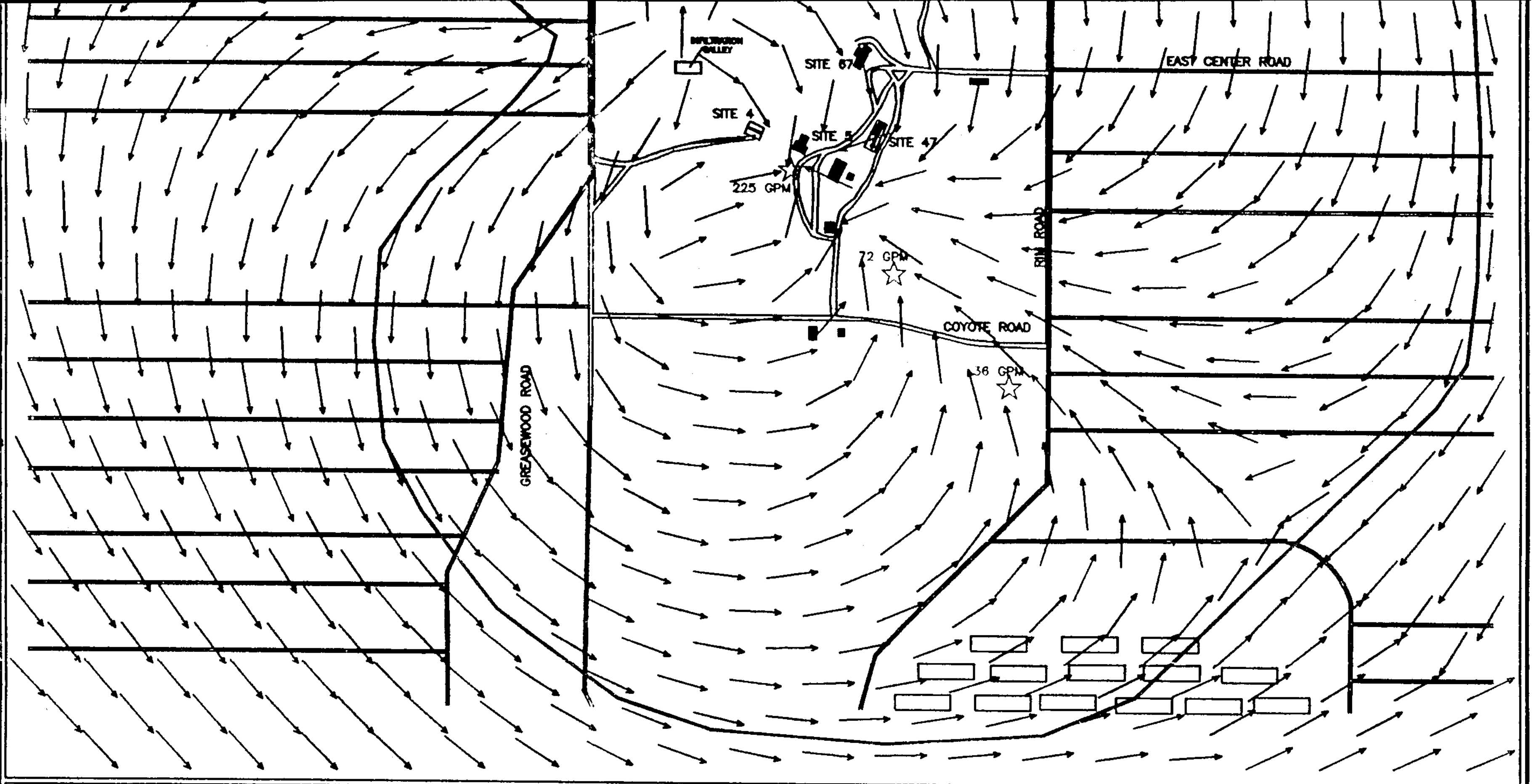
1 of 2


INFILTRATION GALLERY
SITE 67
SITE 4
SITE 5
SITE 47
225 GPM
72 GPM
36 GPM
EAST CENTER ROAD
RIM ROAD
COYOTE ROAD
GREASEWOOD ROAD

PREPARED FOR:
USAEC

DATE:
DEC. '93

DWG. NO.:
67062-048

SCALE:
0 3000 FT.

☆ 36 GPM Extraction Well Location Extraction Flow Rate

→ Ground Water Gradient Direction

— Approximate Contaminant Capture Zone

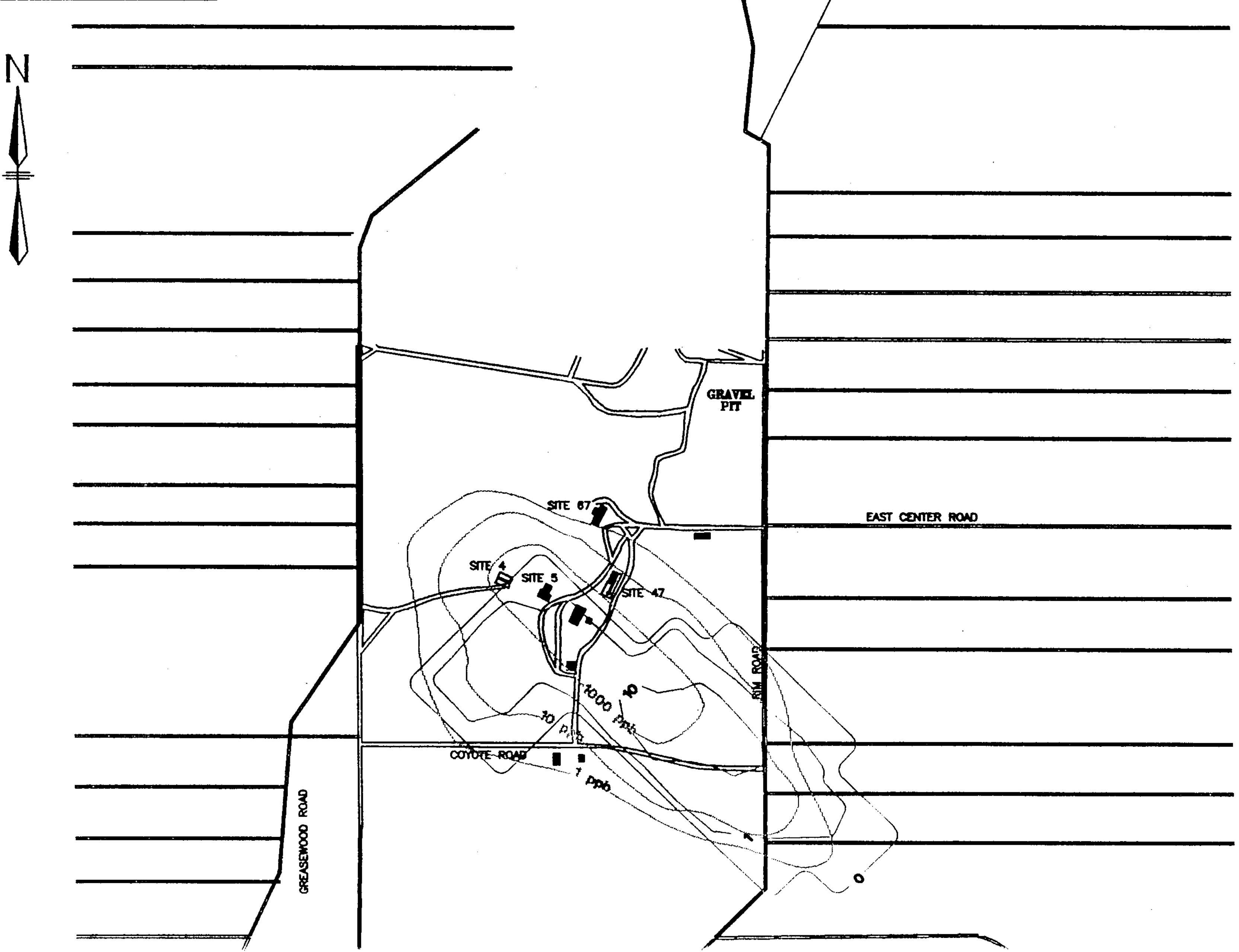
Arthur D Little

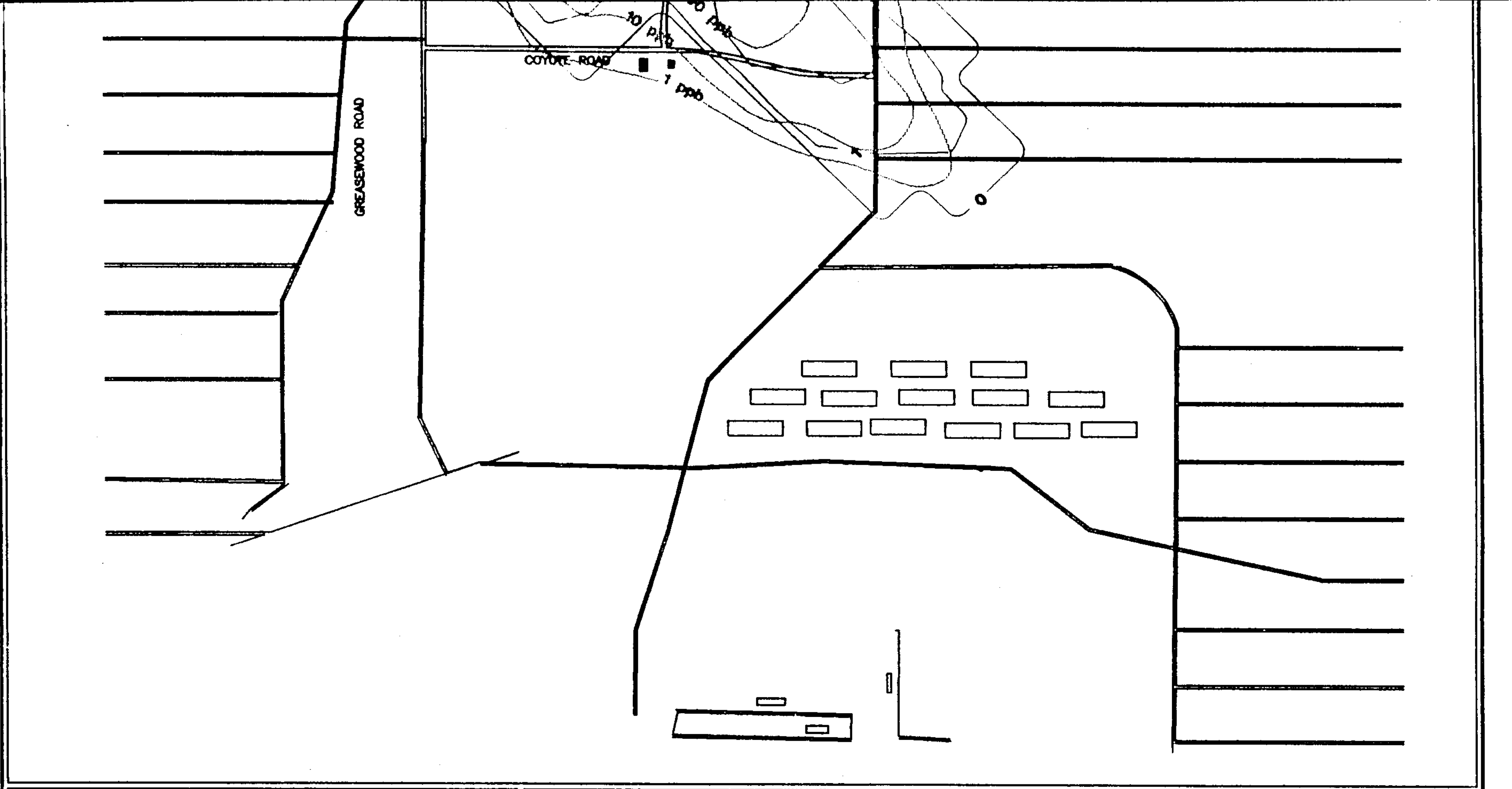
TITLE:

Approximate Contaminant Capture Zone For the 10-Year Extraction System 10^{-6} Risk Level

Figure 4.2.4-1: Approximate Contaminant Capture Zone for the 10-Year Extraction System 10^{-6} Risk Level

REV. #	REVISION DATE
0	12/03/93


N
GRAVEL PIT
SITE 67
EAST CENTER ROAD
SITE 4
SITE 5
SITE 47
RIM ROAD
1000 ppb
10
10 ppb
COYOTE ROAD
1 ppb
0
GREASEWOOD ROAD


0 ppb
10 ppb
1 ppb
0
COYOTE ROAD
GREASEWOOD ROAD

PREPARED FOR:
USAEC

DATE:
DEC. '93

DWG. NO.:
67062–056

SCALE:
0 3000 FT.

——— **Simulated RDX Concentrations after 5 years (ppb)**

········ **Simulated Current RDX Concentrations (ppb)**

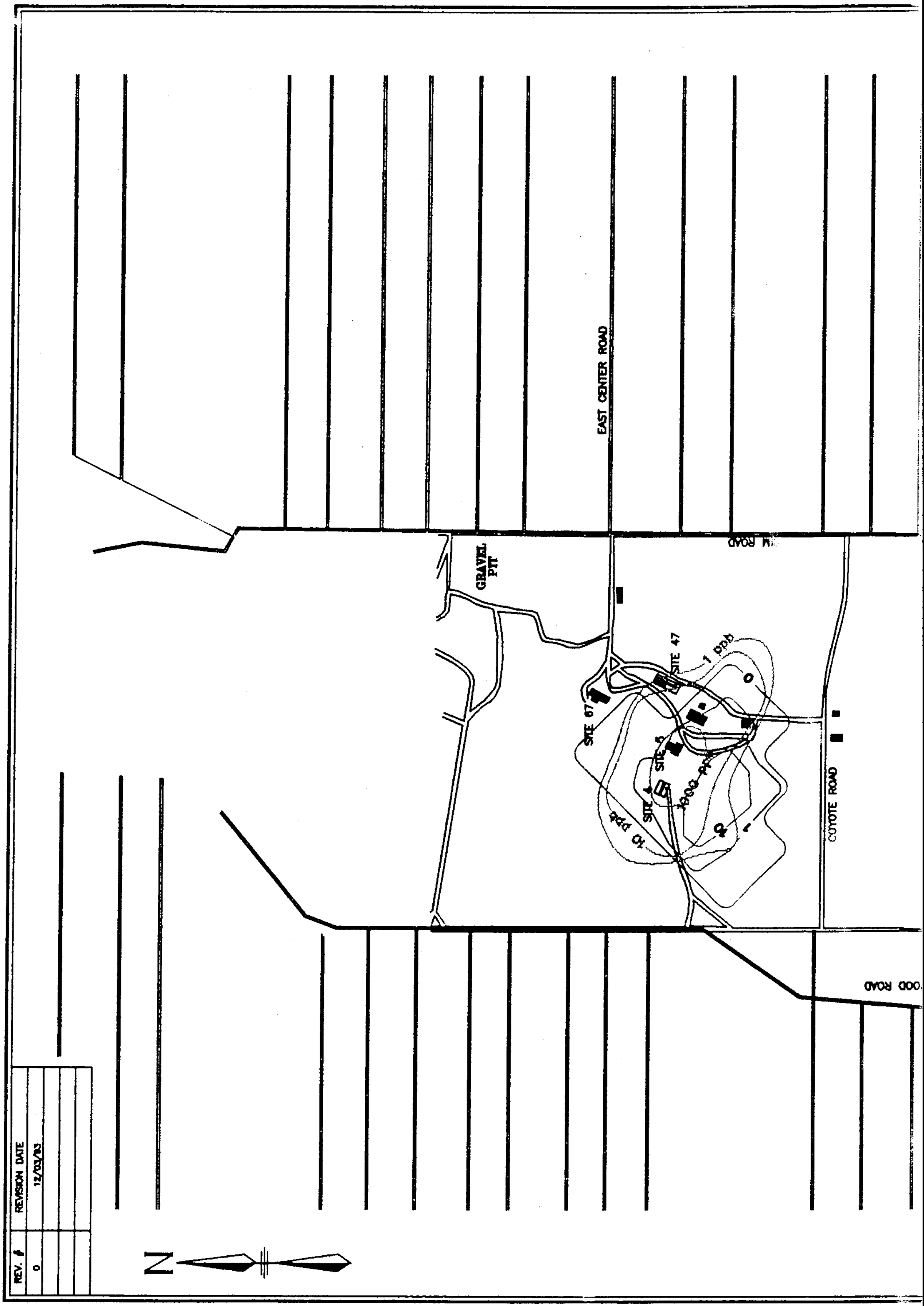
Source: Arthur D. Little, Inc.

Arthur D Little

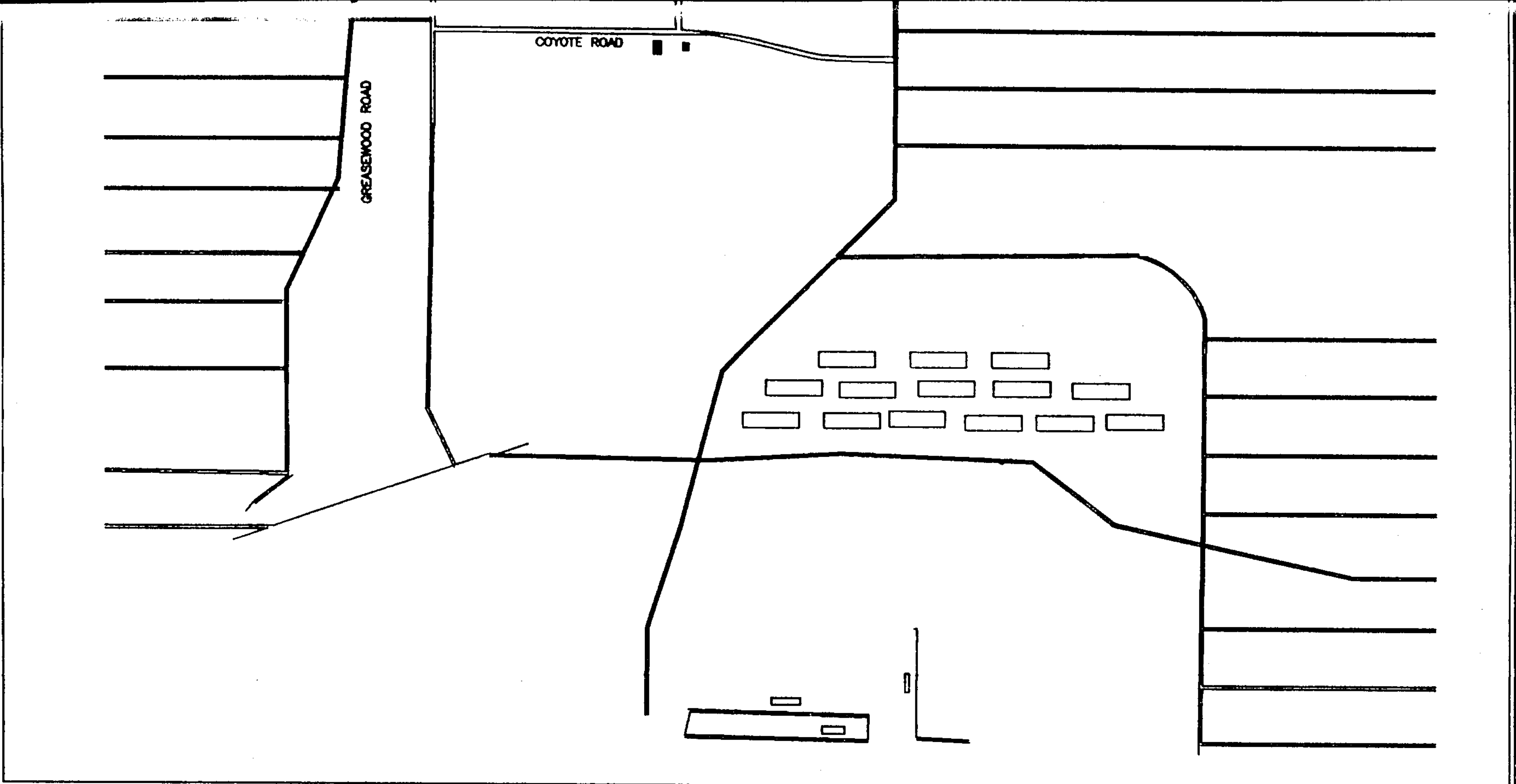
TITLE:

Simulated RDX Concentrations after 5 years with a Remediation Objective of an Incremental Risk of 1 x 10^{-6} and a Hazard Index of 1

Figure 4.2.4-2: Simulated RDX Concentrations After 5 Years


EAST CENTER ROAD
GRAVEL PIT
M ROAD
SITE 47
1 ppb
SITE 67
SITE 6
1000 ppb
SITE 4
10 ppb
COYOTE ROAD
OOD ROAD
REV. #
REVISION DATE
0
12/03/93
N

1 of 3



PREPARED FOR:
USAEC

DATE:
DEC. '93

DWG. NO.:
67062-058

SCALE:
0 3000 FT.

——— **Simulated TNT Concentrations after 5 years (ppb)**

- - - - **Simulated Current TNT Concentrations (ppb)**

Source: Arthur D. Little, Inc.

Arthur D Little

TITLE:

Simulated TNT Concentrations after 5 years with a Remediation Objective of an Incremental Risk of 1 x 10^{-6} and a Hazard Index of 1

Figure 4.2.4-3: Simulated TNT Concentrations After 5 Years

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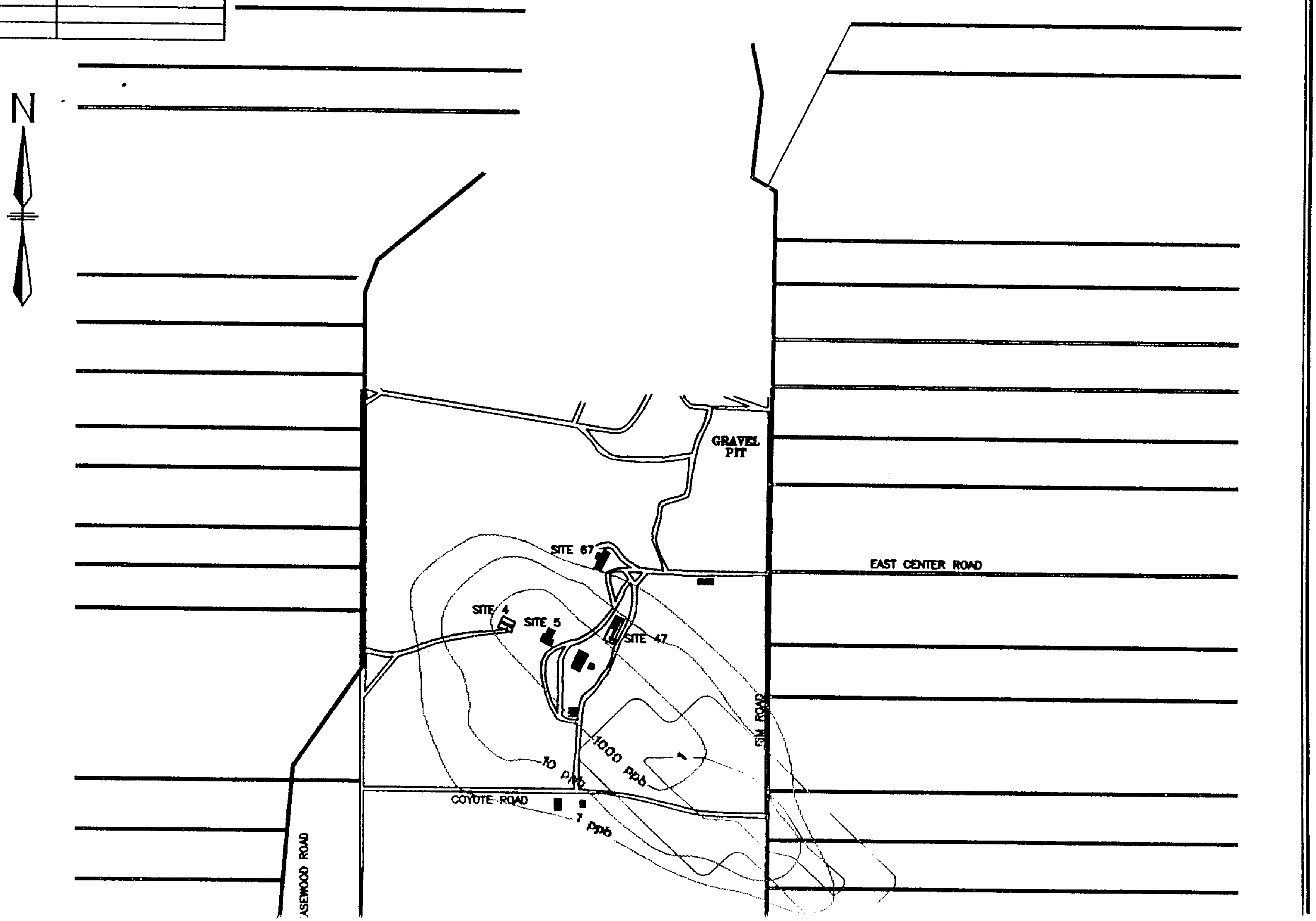
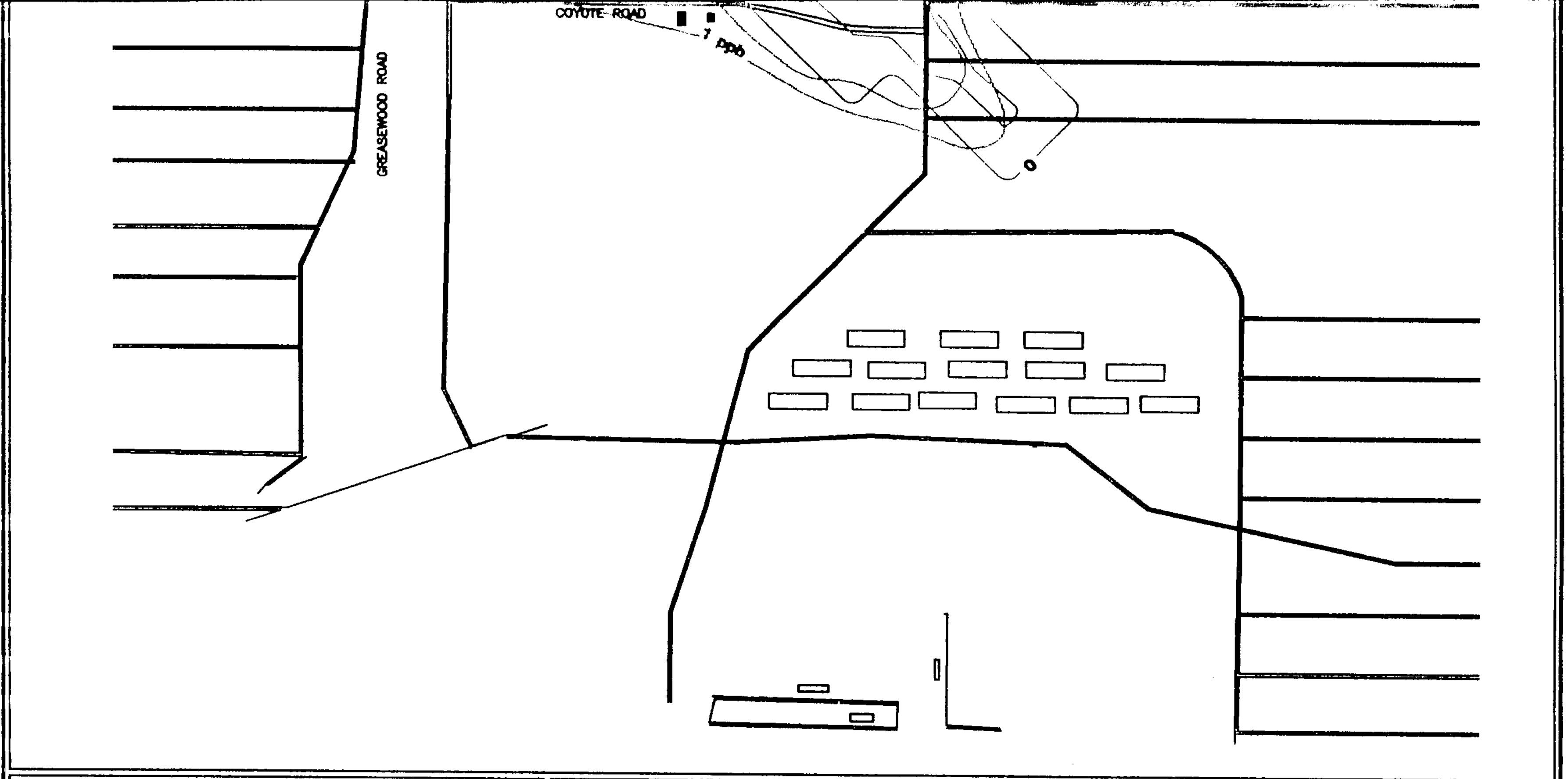
REV. #	REVISION DATE
0	12/03/93


N
GRAVEL PIT
SITE 67
EAST CENTER ROAD
SITE 4
SITE 5
SITE 47
SIM ROAD
1000 ppb
10 ppb
1 ppb
COYOTE ROAD
ASEWOOD ROAD

1 of 2



PREPARED FOR:
USAEC

DATE:
DEC. '93

DWG. NO.:
67062–055

SCALE:
0 3000 FT.

— Simulated RDX Concentrations after 10 years (ppb)

— Simulated Current RDX Concentrations (ppb)

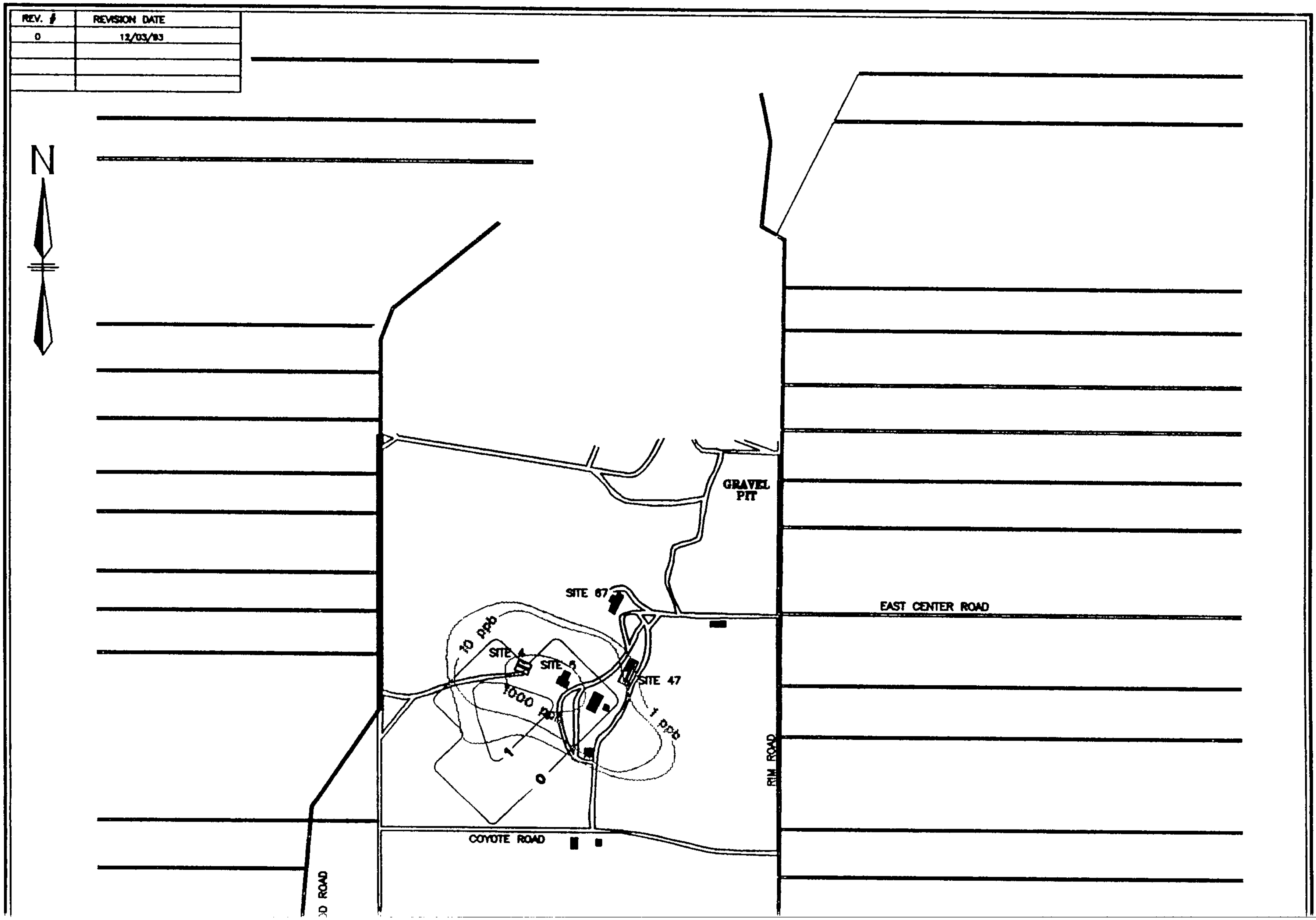
Source: Arthur D. Little, Inc.

Arthur D Little

TITLE:

Simulated RDX Concentrations after 10 years with a Remediation Objective of an Incremental Risk of 1 x 10^{-6} and a Hazard Index of 1

Figure 4.2.4-4: Simulated RDX Concentrations After 10 Years


N
GRAVEL PIT
SITE 67
EAST CENTER ROAD
10 ppb
SITE 4
SITE 5
SITE 47
1000 ppb
1 ppb
1
0
RIM ROAD
COYOTE ROAD
D ROAD

REV. #	REVISION DATE
0	12/03/93

1 of 2

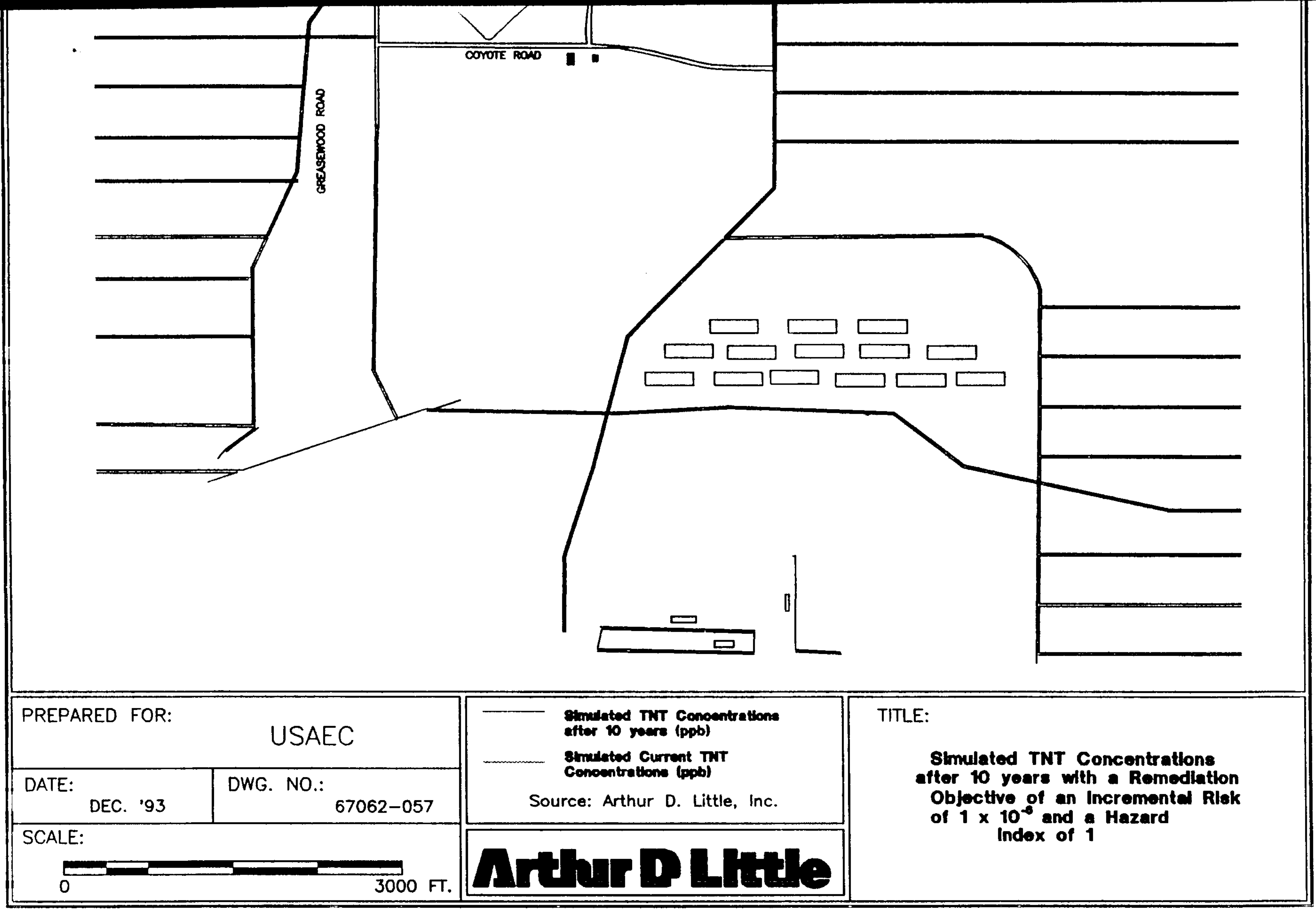

COYOTE ROAD
GREASEWOOD ROAD
PREPARED FOR:
USAEC
DATE:
DEC. '93
DWG. NO.:
67062–057
SCALE:
0
3000 FT.
Simulated TNT Concentrations after 10 years (ppb)
Simulated Current TNT Concentrations (ppb)
Source: Arthur D. Little, Inc.
Arthur D Little
TITLE:
Simulated TNT Concentrations after 10 years with a Remediation Objective of an Incremental Risk of 1 x 10-6 and a Hazard Index of 1

Figure 4.2.4-5: Simulated TNT Concentrations After 10 Years

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4.2.4.6 Ultraviolet/ Oxidation.

4.2.4.6.1 Metal Precipitation. The metal precipitation method for this ground water alternative would be identical to the metal precipitation method described for Alternative 3A (see Section 4.2.3.6.1, Metal Precipitation), except that operating parameters, and where appropriate the volume of material required on a daily basis, for the operation of such a metal precipitation system at the flow rate for this alternative would be:

Parameter	**Operating Condition**
$KMnO_4$ Dose	40 mg/L (73 kg/day)
Operating pH	11.0 units
NaOH Dose	400 mg/L (723 kg/day 50% NaOH)
Anionic Polymer Dose	3 mg/L (5.4 kg/day)
H_2SO_4 Dose	490 mg/L (886 kg/day 50% H_2SO_4)
Sludge Production	1.2 tons/day (@ 30% solids)

4.2.4.6.2 UV/Oxidation. The ultraviolet/oxidation method for this alternative would be identical to the method described for Alternative 3A (see Section 4.2.3.6.2, UV/Oxidation) and will not be repeated here.

4.2.4.6.3 GAC Polishing. The GAC polishing method for this alternative would be identical to the method described for Alternative 3A (see Section 4.2.3.6.3, GAC Polishing) and will not be repeated here.

4.2.4.7 Reinfiltration. For approximately the first six months, 200 gpm will be infiltrated into the washout lagoons to flush the soils. The additional 133 gpm will be pumped to the reinfiltration galleys upgradient of the washout lagoons. After six months all 333 gpm will be sent to the reinfiltration galleys. The reinfiltration method for this alternative would consist of a slightly larger reinfiltration galley, approximately 5,326 square feet, but would otherwise be identical to the system described for Alternative 3A (see Section 4.2.3.7, Reinfiltration). A description of this process will not be repeated here.

4.2.4.8 Capital Cost. The capital cost for the UV/oxidation system is approximately $3.7 million as presented in Table 4.2.4-1. The capital cost of this alternative is strongly dependent on the cost of the UV/oxidation system, which is approximately 50% of the overall capital cost. The cost of the UV/oxidation system would be increased if the volume of water to be treated increased or the retention time to reach the preliminary remedial goals increased. If the water volume to the UV system was increased or the retention time was increased by 50% the capital cost would be increased from $3.7 million to $4.4 million. The capital cost would also be increased if the number of extraction wells needed to be increased to ensure that the capture zone

Table 4.2.4-1: Capital Cost for Ultraviolet/Oxidation – Alternative 3B

Item No.	Item	Units	Unit Cost (1993 $)	# of Units	Total Cost (1993 $)
100	**Extraction**				
101	GW Wells - 8 inch, 155 feet	Well	30,000	3	90,000
102	GW Well Pumps - 250 gpm, 7.5 hp	Pump	2,550	3	7,650
103	GW Buried Pipeline	Pipeline/500 ft	4,250	6	25,500
200	**Equalization**				
201	Equalization/Settling - 18,000 gal	Tank	50,800	1	50,800
202	Feed Pump - 350 gpm, 7 hp	Pump	2,800	2	5,600
300	**Metal Precipitation**	System	296,000	1	296,000
301	pH Control System				
302	Oxidant Addition Pump				
303	Treatment Tank with Mixer				
304	Polymer Feed System				
305	Clarification System				
306	Sludge Thickening System				
307	Filter Press				
308	Multi-Media Filter				
400	**UV/Oxidation**	System	1,560,000	1	1,560,000
401	UV Reactor				
402	UV Feed Pump				
403	Ozone Generation and Destruction				
500	**Granular Activated Carbon**				
501	GAC Tank - 2000 gal	Tank	4,250	2	8,500
502	GAC - 2000 lb	Bed	4,500	2	9,000
503	Discharge Pump - 350 gpm, 8 hp	Pump	2,900	2	5,800
600	**Reinfiltration Galley**				
601	Excavation	C.Y.	2	2,177	4,898
602	Crushed Stone	C.Y.	19	725	13,848
603	Backfill	C.Y.	2	217	365
604	Infiltration Galley	Galley	200	333	66,600
700	**Lagoon Lining**				
701	HDPE Liner	Lagoon	3000	2	6,000
702	Crushed Stone	C.Y.	19.1	520	9,932
Equipment Subtotal					**$2,160,492**
Remedial Design / Planning		10 % of Purchased Equipment Cost			216,049
Plumbing		10 % of Purchased Equipment Cost			216,049
Electrical		10 % of Purchased Equipment Cost			216,049
Instrumentation and Controls		10 % of Purchased Equipment Cost			216,049
Construction and Installation		30 % of Purchased Equipment Cost			648,148
Treatment System Building		sq feet	27	1,200	32,400
Installation Subtotal					**$1,544,745**
Total Capital Cost					**$3,705,237**

Source: Arthur D. Little, Inc.

was maintained; if the number of wells was doubled the total capital cost would only be increased by approximately $175,000.

4.2.4.9 Operating Cost. The annual operating cost for the UV/oxidation system is approximately $1.6 million, as presented in Table 4.2.4-2. Using the annual operating cost, the NPV was calculated for the 10-year scenario using a 5% and a 10% interest rate.

		5% Interest Rate		10% Interest Rate	
Time Frame	**Annual Cost**	**Discount Factor**	**NPV**	**Discount Factor**	**NPV**
1-10 years	$1.6M	7.9	$12.6M	6.0	$9.6M

The operating cost for this alternative is strongly dependent on the electrical cost for the operation of the UV/oxidation system. The electrical cost would increase if the size of the UV/oxidation system was increased. A 50% increase in the size of the UV/oxidation system would increase the electrical costs from $900,000 to $1,100,000, and the 5% NPV would increase from $12.6 million to $14.3 million.

4.2.4.10 NCP Evaluation Criteria. The degree to which UV/oxidation of the contaminated ground water meets the NCP evaluation criteria is discussed below.

Overall Protection of Human Health and the Environment

This alternative would return the ground water to its potential beneficial use within 10 years. Upon achieving the remedial action objectives, the total hazard index for the ingestion of ground water for all compounds, at reasonable maximum exposure, would be reduced from 60 to 2.0. The total incremental cancer risk for the ingestion of ground water for all compounds at reasonable maximum exposure would be reduced from $2x10^{-3}$ to $1.3x10^{-5}$ (see Section 2.1, Remedial Action Objectives).

The alternative would also provide treatment for the contamination on site, except for small volumes of residuals such as the metal hydroxide sludge for the precipitation system and the spent carbon from the polishing system. The alternative would not pose a short-term risk to human health or the environment and would maximize the amount of water that was returned to the aquifer.

Compliance with ARARs

The alternative would meet the preliminary remediation goals in 10 years. The alternative would meet all action-specific ARARs, including:

Table 4.2.4-2: Annual Operating Cost for Ultraviolet/Oxidation - Alternative 3B

Item	Units	Units/ Year	Unit Cost (1993 Dollars)	Annual Cost (1993 Dollars)
Variable Cost				
Monitoring				
Sample Collection	hours	640	30	19,200
Supervision	hours	32	50	1,600
Sample Analysis	samples	152	150	22,800
Data Review and Reporting	hours	32	65	2,080
Five -Year Review (a)	hours	50	80	4,000
Metals Precipitation (b)	1000 gal (c)	173,448	0.4	69,379
Electrical (d)	kw/yr	15,000,000	0.06	900,000
Ozone	1000 gal (c)	173,448	0.25	43,362
Granular Activated Carbon				
GAC Bed - 2000 lbs	ton	5.6	4500	25,200
GAC Incineration (e)				
Polyethylene Lined Drums	drum	33.4	25	835
Shipping	drum	33.4	125	4,175
Treatment/Disposal	drum	33.4	420	14,028
Disposal (f)	ton	455	300	136,500
Operational Monitoring	samples	100	150	15,000
Labor				
Operator (g)	hours	2,500	30	75,000
Supervisor (h)	hours	200	50	10,000
Variable Cost Subtotal				**$1,343,159**
Fixed Cost				
Maintenance				
Labor and Materials	7% of Capital Investment			259,370
Fixed Cost Subtotal				**$259,370**
Total Annual Operating Cost				**$1,602,529**

Notes:
(a) – The cost for the Five-Year Review has been divided evenly over five years
(b) – Operating cost for metal precipitation includes power and chemicals
(c) - Untreated ground water
(d) – Electrical includes power for pumps, UV lights, and misc. electrical for heating building, lighting, etc.
(e) - Assumes 335 pounds of dewatered GAC/55 gallon drum
(f) – Includes disposal of any solids or from equilization tank and disposal of metal hydroxide sludge from metal precipitation
(g) – Two operators on-site 3.0 days/week
(h) – One supervisor 4 hours/week to review operation of process

Source: Arthur D. Little, Inc.

- No state and federal safe drinking water regulations exist for the contaminants of concern; therefore, the ground water will be treated to ensure that each compound meets a hazard index of 1 and an excess cancer risk of 10^{-6} prior to its return to the aquifer.

- State surface water discharge or underground injection regulations on the disposal of the treated ground water.

- All RCRA requirements will be met in regard to the transport and disposal of the residuals from the treatment process. The explosive concentration in the spent carbon will be equal to or less than 7%, which is well below the explosive limit of 10% (Arthur D. Little, 1987). A TCLP analysis of the spent GAC would have to be performed to ensure that the DNT concentration was below the RCRA limit.

Long-Term Effectiveness

The residual risk that would remain on site due to contamination in the ground water would be reduced to a hazard index of 2 and a carcinogenic risk of 1.3×10^{-5} in 10 years. Without active contamination treatment, the risk reduction would not be reached for 5,000 years.

Treatment residuals that are generated during the remediation of the ground water would be disposed of in a manner to eliminate unacceptable risks. The metal hydroxide sludges from the metal precipitation unit would be disposed of in a hazardous waste landfill, and the contaminants adsorbed on the spent GAC would be destroyed by off-site incineration or by another type of thermal treatment (e.g., regeneration or a cement kiln). Any free product removed from the equalization tank would be shipped off-site for treatment and disposal.

The alternative would be operated until the ground water met the preliminary remedial goals, and the contaminants would be either destroyed in the UV/oxidation system or when the carbon is incinerated or by another type of thermal treatment (e.g., regeneration or a cement kiln). Therefore, no long-term controls would be necessary. All the technologies that would be used in this alternative are considered reliable.

This alternative would require five-year reviews to evaluate whether the alternative is protective of public health and the environment. The five-year reviews would be initiated five years after the start of the remedial action and would continue until no contaminants remain at the site above levels that allow for unrestricted use and unlimited exposure.

Reduction of Toxicity, Mobility, or Volume Through Treatment

The UV/oxidation system would irreversibly destroy the contaminants directly by oxidizing the contaminants. Any remaining contaminants would be removed by the liquid phase GAC system. The UV/oxidation system would remove approximately 90% of the contamination from the ground water stream (ICF Kaiser Engineers, 1993). The remaining contaminants would be treated using the liquid phase GAC system. The contamination adsorbed on the liquid phase GAC will be irreversibly destroyed by off-site incineration of the carbon or by another type of thermal treatment (e.g., regeneration or a cement kiln). This treatment system will reduce the volume, toxicity, and mobility of the contaminants.

The metal precipitation system will generate metal hydroxide sludges at a rate of approximately 455 tons/year. These sludges will be disposed of off site as a hazardous waste. In addition to the sludges, an estimated 200 pounds of sediment will be collected each year in the equalization tank that will be analyzed and disposed of on site if found to be free of contamination.

Short-Term Effectiveness

The operation of the UV/oxidation system is not expected to increase the risk to the community because the contaminants will be irreversibly destroyed or adsorbed on the GAC and incinerated off site. The risks to the workers from using the acids, bases, and ozone would be minimized through the use of engineering controls and personal protective equipment.

The alternative would meet the remedial action objectives within 10 years. If no active remediation alternative is implemented at the site, the ground water will not meet the remedial action objectives for an estimated 5,000 years.

Implementation

The construction and operation of the UV/oxidation system can be easily implemented and is technically capable of treating the contaminants in the ground water. The capacity of the UV/oxidation system can be increased if additional ground water needs to be treated or the concentration of contamination is greater than expected.

There is some uncertainty surrounding the reinfiltration of treated ground water into the lagoons to flush the remaining contaminants from the soils. Because there is the potential for the reinfiltration spreading the contamination, the ground water in the vicinity of the lagoons will have to be monitored to ensure that reinfiltration is not adversely affecting the ability to remediate the ground water. If there is a concern, then the ground water will be switched to the reinfiltration galleys upgradients.

No special equipment, materials, or technical specialists would be required for the implementation of the UV/oxidation system. Vendors are also currently available for the supply and incineration of the GAC.

State and local coordination would be required for the implementation of legal restrictions on the use of ground water at the site and the discharge of treated ground water to the environment.

Cost

The capital and operating costs are presented in Section 4.2.4.8 and Section 4.2.4.9, respectively.

4.2.5 Alternative 4A - Carbon Adsorption (30 Years, Remediated to Preliminary Remedial Goals)

In this alternative, the ground water will be extracted from a series of three wells over a thirty year period to remediate the ground water to preliminary remedial goals as shown in Section 2.1.5, Preliminary Remediation Goals for Ground Water (2.1 μg/L for RDX and 2.8 μg/L for TNT). The ground water will be treated by granular activated carbon (GAC) to remove the explosives (Figure 4.2.5-1).

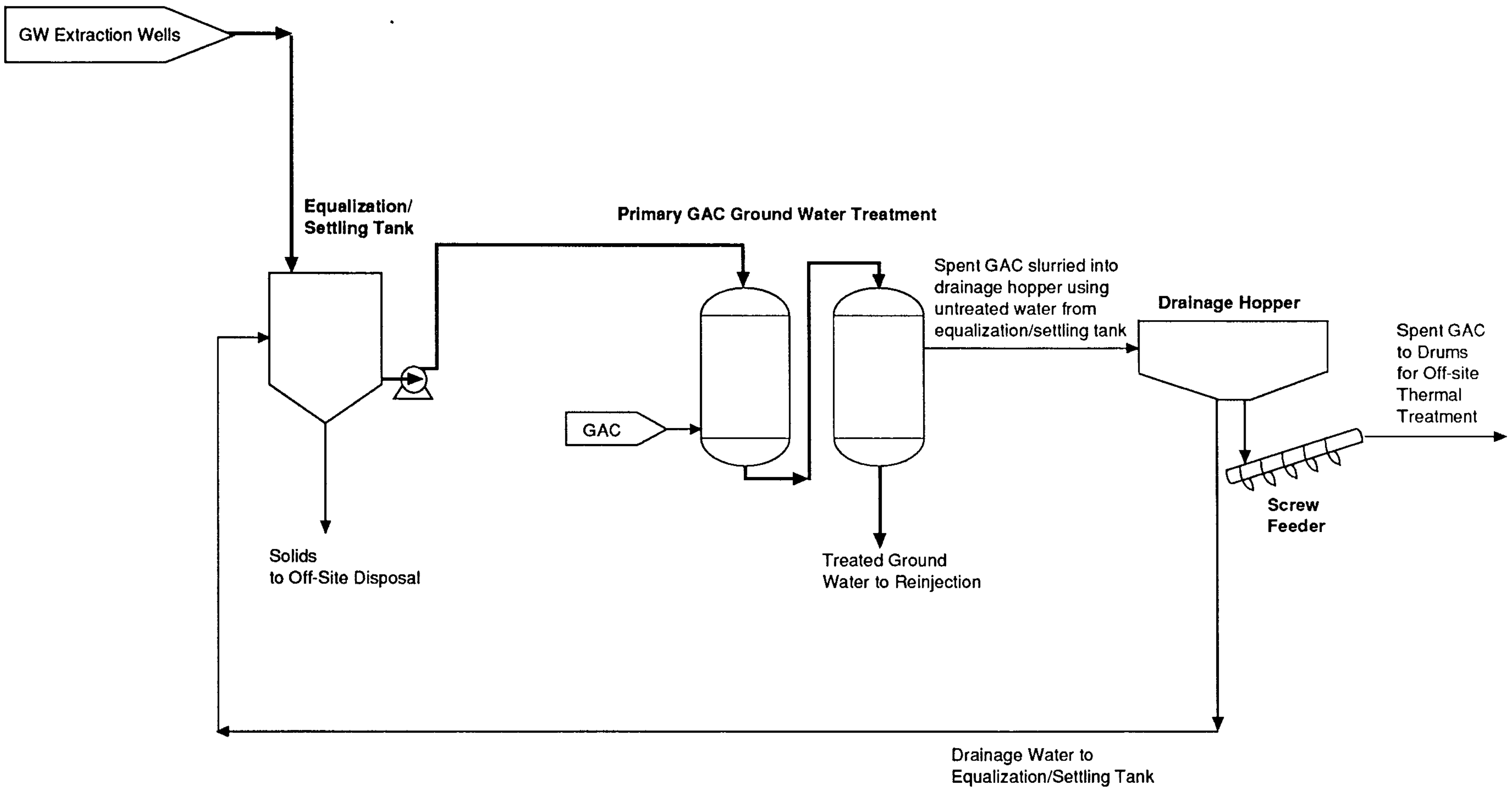
After the ground water has been treated and meets all preliminary remediation goals, it will initially be pumped to the explosive washout lagoons, where it will be allowed to reinfiltrate into the soils under the lagoons. Reinfiltration of the treated ground water into the lagoons will flush the remaining soil contamination into the ground water table, where it will be collected downgradient in the extraction wells. After approximately eight months the reinfiltration of the treated ground water will be moved to infiltration galleys 400 to 800 feet upgradient of the lagoons.

The GAC option would be designed to handle the same ground water flow rates and contaminant concentrations as the UV/oxidation system described in Section 4.2.3, Alternative 3A, and depicted in Figure 4.2.3-1. The spent carbon from the GAC treatment beds would be incinerated off site at any of the commercial hazardous waste incinerators (or a cement kiln) described in Section 4.2.5.6; each of the incinerators listed in this section is capable of treating the spent carbon from this treatment system. Regeneration of the spent carbon contaminated with explosives is not currently considered feasible due to the destruction of carbon particles during regeneration; however, if the regeneration process becomes feasible during the remedial action, regeneration would be considered.

In addition, this alternative will require ground water monitoring, five-year reviews, and institutional controls, which will continue until the contamination has been remediated to the detection limits stated above.

4.2.5.1 Institutional Controls. While the ground water is being remediated, institutional controls will be needed to restrict access to the contaminated aquifer, the contaminated ground water remediation equipment and the interconnecting piping. The

Figure 4.2.5-1: Conceptual Flow Diagram of Primary GAC Treatment of Contaminated Ground Water


GW Extraction Wells
Equalization/ Settling Tank
Primary GAC Ground Water Treatment
GAC
Spent GAC slurried into drainage hopper using untreated water from equalization/settling tank
Drainage Hopper
Spent GAC to Drums for Off-site Thermal Treatment
Screw Feeder
Solids to Off-Site Disposal
Treated Ground Water to Reinjection
Drainage Water to Equalization/Settling Tank

Source: Arthur D. Little, Inc.

level of institutional controls is similar to that previously discussed in Section 4.2.2, Alternative 2, and will not be repeated here.

4.2.5.2 Monitoring. The monitoring program would sample the existing monitoring wells and is identical to the program presented in Section 4.2.2.2, Monitoring for the Institutional Control Alternative.

4.2.5.3 Five-Year Reviews. In addition to the monitoring of the ground water and the institutional controls, this alternative would also require five-year reviews intended to evaluate whether the alternative remains protective of public health and the environment. The five-year reviews would be initiated five years after the start of the remedial action and continue until no contaminants remain at the site above levels that allow for unrestricted use and unlimited exposure. These reviews would be identical to the reviews described for the No Action alternative (see the introduction to Section 4.2, Individual Analysis of Alternatives).

4.2.5.4 Ground Water Extraction. The extraction method for this ground water alternative would be identical to the extraction method described for Alternative 3A (see Section 4.2.3.4, Ground Water Extraction). Figure 4.2.3-1 presents the extraction well locations and the predicted ground water capture zones when the extraction wells are operating. Intermediate (15 years) and final (30 years) contour maps are presented in Figures 4.2.3-3 to 4.2.3-6. These figures, along with the capture zone, demonstrate that this alternative will remediate the site and capture the reinfiltrated ground water.

4.2.5.5 Equalization. The equalization method for this ground water alternative would be identical to the equalization method described for Alternative 3A (see Section 4.2.3.5, Equalization). The extracted ground water would be pumped to a 7,000-gallon equalization tank that would provide an approximately 50-minute retention time.

4.2.5.6 GAC Primary Treatment. The ground water would be pumped from the equalization tank to the GAC primary treatment beds without metals precipitation. The primary treatment carbon adsorbers would be sized to remove the explosive ground water contaminants to preliminary remedial goals without the use of any other treatment.

The GAC polishing unit would consist of two parallel treatment trains consisting of 2,000-pound carbon beds contained in tanks sized to allow for adequate absorbent time. The carbon beds would not be operated until saturation, but rather only until an average 0.07 lb contaminant per lb GAC loading was achieved. This ceiling on loading is to ensure that the adsorbed contaminant/GAC matrix does not approach its explosive limit. When test results indicated that the carbon bed was spent, the polishing system would be switched over to the standby bed. Carbon usage would be approximately 125 lb/day; therefore, each carbon bed is expected to last approximately 16 days based upon the design flow rate (see Appendix C).

To change the spent carbon, untreated water from the equalization vessel would be used to slurry the column into a hopper. The GAC would be allowed to gravity drain for approximately 24 hours, and would then be screw-fed from the hopper into drums. The water drained from the hopper would be collected and recirculated back to the equalization vessel for treatment.

The drums containing the spent, but not saturated, carbon would be shipped off site for thermal treatment (e.g., incineration, cement kiln, regeneration). Incineration was selected for costing purposes in the FS because it is the most common disposal method for explosive ladden GAC at explosive manufacturing plants (Arthur D. Little, 1993). Several commercial incineration facilities were determined to be capable of handling explosive-laden GAC in bulk or drum. These commercial facilities included: the Chemical Waste Management incinerators in Port Arthur, Texas and Chicago, Illinois, the Rollins Environmental Services Incinerators in Deer Park, Texas and Lake Charles, Louisiana, as well as the ENSCO incinerator in El Dorado, Arkansas, which is a Defense Logistics Agency-approved site. GAC incineration costs included in this section were based on the average per drum cost obtained from personnel at these facilities. To minimize costs and risks associated with transportation, it would be desirable to use an incineration facility close to the site; however, the closest incineration facility found to be willing and capable of treating the spent GAC was located in Texas. Additional facilities should be investigated during the Remedial Design.

4.2.5.7 Reinfiltration. The reinfiltration method for this alternative would consist of a reinfiltration galley identical to that described for Alternative 3A (see Section 4.2.3.7, Reinfiltration). A description of the reinfiltration process will not be repeated here.

4.2.5.8 Capital Cost. The capital cost for the GAC treatment system is approximately $0.4 million, as presented in Table 4.2.5-1. The capital cost for the GAC system is spread out fairly evenly between all the unit operations. A moderate increase in the flow rate or the concentration of contaminants in the inlet would not require a larger GAC system. The capital cost would also be increased if the number of extraction wells needed to be increased to ensure that the capture zone was maintained; if the number of wells was doubled the total capital cost would only be increased by approximately $175,000.

4.2.5.9 Operating Cost. The annual operating cost for the GAC treatment system is approximately $0.4 million, as presented in Table 4.2.5-2. Using the annual operating cost, the NPV was calculated for the 30-year scenario using a 5% and a 10% interest rate.

Table 4.2.5-1: Capital Cost for Granular Activated Carbon – Alternative 4A

Item No.	Item	Units	Unit Cost (1993 $)	# of Units	Total Cost (1993 $)
100	**Extraction**				
101	GW Wells - 8 inch, 155 feet	Well	30,000	3	90,000
102	GW Well Pumps - 100 gpm, 3 hp	Pump	1,550	3	4,650
103	GW Buried Pipeline	Pipeline/500 ft	4,250	6	25,500
200	**Equalization**				
201	Equalization/Settling - 7,000 gal	Tank	19,000	1	19,000
202	Feed Pump - 200 gpm, 5 hp	Pump	2,200	2	4,400
300	**Granular Activated Carbon**				
301	GAC Tank - 2000 gal	Tank	4,250	2	8,500
302	GAC - 2000 lb	Bed	4,500	2	9,000
303	Discharge Pump - 200 gpm, 7 hp	Pump	2,300	2	4,600
400	**Reinfiltration Galley**				
401	Excavation	C.Y.	2	909	2,045
402	Crushed Stone	C.Y.	19	302	5,768
403	Backfill	C.Y.	2	90	151
404	Infiltration Galley	Galley	200	140	28,000
500	**Lagoon Lining**				
501	HDPE Lining	Lagoon	3,000	2	6,000
502	Crushed Stone	C.Y.	19	520	9,932
Equipment Subtotal					**$217,547**
Remedial Design / Planning		10 % of Purchased Equipment Cost			21,755
Plumbing		10 % of Purchased Equipment Cost			21,755
Electrical		10 % of Purchased Equipment Cost			21,755
Instrumentation and Controls		10 % of Purchased Equipment Cost			21,755
Construction and Installation		30 % of Purchased Equipment Cost			65,264
Treatment System Building		sq feet	27	1,200	32,400
Installation Subtotal					**$184,683**
Total Capital Cost					**$402,229**

Source: Arthur D. Little, Inc.

Table 4.2.5-2: Annual Operating Cost for Granular Activated Carbon - Alternative 4A

Item	Units	Units/ Year	Unit Cost (1993 Dollars)	Annual Cost (1993 Dollars)
Variable Cost				
Monitoring				
Sample Collection	hours	640	30	19,200
Supervision	hours	32	50	1,600
Sample Analysis	samples	152	150	22,800
Data Review and Reporting	hours	32	65	2,080
Five-Year Review (a)	hours	50	80	4,000
Electrical (b)	kw/yr	424,000	0.06	25,440
Granular Activated Carbon				
GAC Bed - 2000 lbs	Ton	22.8	4500	102,600
GAC Incineration (c)				
Polyethylene Lined Drums	drum	137	25	3,425
Shipping	drum	137	125	17,125
Treatment/Disposal	drum	137	420	57,540
Operational Monitoring	samples	100	150	15,000
Labor				
Operator (d)	hours	2,500	30	75,000
Supervisor (e)	hours	200	50	10,000
Variable Cost Subtotal				$355,810
Fixed Cost				
Maintenance				
Labor and Materials	7% of Capital Investment			28,160
Fixed Cost Subtotal				$28,160
Total Annual Operating Cost				$383,970

Notes:
(a) – The cost for the Five-Year Review has been divided evenly over five years
(b) – Electrical includes power for pumps, and misc. electrical
for heating building, lighting, etc.
(c) - Assumes 335 pounds of GAC/55 gallon drum
(d) – Two operators on-site 3.0 days/week
(e) – One supervisor 4 hours/week to review operation of process

Source: Arthur D. Little, Inc.

Time Frame	Annual Cost	5% Interest Rate Discount Factor	NPV	10% Interest Rate Discount Factor	NPV
1-30 years	$0.4M	15.8	$6.3M	9.9	$4.0M

The carbon purchase and carbon disposal represent the largest operating costs for this alternative. If the flow rate or the contaminant concentration in the inlet to the GAC system was increased by 50% carbon usage would also increase by 50%. This increase in carbon usage would increase the operating costs from $380,000 to $464,000, and the 5% NPV would increase from $6.3 million to $7.8 million.

4.2.5.10 NCP Evaluation Criteria. The degree to which GAC treatment of the contaminated ground water meets the NCP evaluation criteria is discussed below.

Overall Protection of Human Health and the Environment

This alternative would return the ground water to its potential beneficial use within 30 years. Upon achieving the remedial action objectives, the total hazard index for the ingestion of ground water for all compounds, at reasonable maximum exposure, would be reduced from 60 to 2. The total incremental cancer risk for the ingestion of ground water for all compounds at reasonable maximum exposure would be reduced from $2x10^{-3}$ to $1.3x10^{-5}$ (see Section 2.1, Remedial Action Objectives).

Unlike the UV/oxidation alternatives, this alternative would not provide treatment for the contamination on-site. The spent GAC would be sent off-site for thermal destruction. The alternative would not pose a short-term risk to human health or the environment and would maximize the amount of water that was returned to the aquifer.

Compliance with ARARs

The alternative would meet the preliminary remediation goals in 30 years. The alternative would meet all action-specific ARARs, including:

- No state and federal safe drinking water regulations exist for the contaminants of concern; therefore, the extracted ground water will be treated to ensure that each compound meets a hazard index equal to or less than 1, an excess cancer risk of greater than 10^{-6}, or the compound's detection limit prior to its return to the aquifer.
- State surface water discharge or underground injection regulations on the disposal of the treated ground water.
- All RCRA requirements will be met in regard to the transport and disposal of the residuals from the treatment process. The explosive concentration in the spent carbon will be equal to or less than 7%, which is well below the explosive limit of

10% (Arthur D. Little, 1987). A TCLP analysis of the spent GAC would have to be performed to ensure that the DNT concentration is below the RCRA limit.

Long-Term Effectiveness

The residual risk that would remain on site due to contamination in the ground water would be reduced to a hazard index of 2 and a carcinogenic risk of 1.3×10^{-5} in 30 years. Without active contamination treatment, the risk reduction would not be reached for 5,000 years.

Treatment residuals that are generated during the remediation of the ground water would be disposed of in a manner to eliminate unacceptable risks. The spent GAC contaminants would be destroyed at a permitted off site incinerator or by another type of thermal treatment (e.g., regeneration or a cement kiln). Any solids removed from the equalization tank would be shipped off-site for treatment and disposal.

The alternative would be operated until the ground water met the stated cleanup levels for the alternative, and the contaminants would be destroyed when the carbon is incinerated or by another type of thermal treatment (e.g., regeneration or a cement kiln). Therefore, no long-term controls would be necessary. The technologies that would be used in this alternative are considered to be reliable and have been proven at other similar sites.

This alternative would require five-year reviews to evaluate whether the alternative is protective of public health and the environment. The five-year reviews would be initiated five years after the start of the remedial action and would continue until no contaminants remain at the site above levels that allow for unrestricted use and unlimited exposure.

Reduction of Toxicity, Mobility, or Volume Through Treatment

The contaminants would be treated using the GAC system; any contamination adsorbed on the GAC will be irreversibly destroyed by incineration of the carbon or by another type of thermal treatment (e.g., regeneration or a cement kiln). This treatment system will reduce the volume, toxicity, and mobility of the contaminants.

The primary GAC treatment system will generate approximately 23 tons/year of spent carbon for off-site incineration. In addition to the spent GAC, an estimated 100 pounds of sediment will be collected each year in the equalization tank that will be analyzed and disposed of on site if found to be free of contamination.

Short-Term Effectiveness

The operation of the GAC treatment system is not expected to increase the risk to the community or the environment because the contaminants will be adsorbed on the GAC and thermally destroyed. The risks to the workers and the environment from accumulation of explosive levels of contaminants on the GAC would be minimized through the operational limit on allowable capacity, as well as the use of engineering controls and personal protective equipment.

The alternative would meet the remedial action objectives within 30 years. If no active remediation alternative is implemented at the site, the ground water will not meet the remedial action objectives for an estimated 5,000 years.

Implementation

The construction and operation of the GAC treatment system can be easily implemented and is technically capable of treating the contaminants in the ground water. The capacity of the GAC system can be increased if additional ground water needs to be treated or the concentration of contamination is greater than expected. The design of the treatment system will also facilitate system scale-down as the contaminant loading decreases over the life of the project.

There is some uncertainty surrounding the reinfiltration of treated ground water into the lagoons to flush the remaining contaminants from the soils. Because there is the potential for the reinfiltration spreading the contamination, the ground water in the vicinity of the lagoons will have to be monitored to ensure that reinfiltration is not adversely affecting the ability to remediate the ground water. If there is a concern, then the ground water will be switched to the reinfiltration galleys upgradient.

No special equipment, materials, or technical specialists would be required for the implementation of the system. Vendors are also currently available for the supply and incineration of the GAC.

State and local coordination would be required for the implementation of legal restrictions on the use of ground water at the site and the discharge of treated ground water to the environment.

Cost

The capital and operating costs are presented in Section 4.2.5.8 and Section 4.2.5.9, respectively.

4.2.6 Alternative 4B - Carbon Adsorption (10 Years, Remediated to Preliminary Remedial Goals)

In this alternative, the ground water will be extracted from a series of three wells over a 10-year period to remediate the ground water to preliminary remedial goals as shown in Section 2.1.5, Preliminary Remediation Goals for Ground Water (2.1 µg/L for RDX and 2.8 µg/L for TNT). The ground water will be treated by granular activated carbon (GAC) to remove the explosives (See Figure 4.2.5-1).

After the ground water has been treated to meet all preliminary remediation goals, 200 gpm will initially be pumped to the explosive washout lagoons, where it will be allowed to reinfiltrate into the soils under the lagoons. The additional 130 gpm will be pumped to the reinfiltration galleys. Reinfiltration of the treated ground water into the lagoons will flush the remaining soil contamination into the ground water table, where it will be collected downgradient in the extraction wells. After approximately six months the reinfiltration of the treated ground water will be moved to infiltration galleys 400 to 800 feet upgradient of the lagoons.

The GAC option would be designed to handle the same ground water flow rates and contaminant concentrations as the UV/oxidation system described in Section 4.2.4, Alternative 3B, and depicted in Figure 4.2.4-1. The spent carbon from the GAC treatment beds would be incinerated off site at any of the commercial hazardous waste incinerators (or a cement kiln) described in Section 4.2.5.6; each of the incinerators listed in this section is capable of treating the spent carbon from this treatment system. Regeneration of the spent carbon contaminated with explosives is not currently considered feasible due to the destruction of carbon particles during regeneration; however, if the regeneration process becomes feasible during the remedial action, regeneration would be considered.

In addition, this alternative will require ground water monitoring, five-year reviews, and institutional controls, which will continue until the contamination has been remediated to the detection limits stated above.

4.2.6.1 Institutional Controls. While the ground water is being remediated, institutional controls will be needed to restrict access to the contaminated aquifer, the contaminated ground water remediation equipment and the interconnecting piping. The level of institutional controls is similar to that previously discussed in Section 4.2.2, Alternative 2, and will not be repeated here.

4.2.6.2 Monitoring. The monitoring program would sample the existing monitoring wells and is identical to the program presented in Section 4.2.2.2, Monitoring, for the Institutional Control Alternative.

4.2.6.3 Five-Year Reviews. In addition to the monitoring of the ground water and the institutional controls, this alternative would also require five-year reviews intended to evaluate whether the alternative remains protective of public health and the environment. The five-year reviews would be initiated five years after the start of the remedial action and continue until no contaminants remain at the site above levels that allow for unrestricted use and unlimited exposure. These reviews would be identical to the reviews described for the No Action alternative (see the introduction to Section 4.2, Individual Analysis of Alternatives).

4.2.6.4 Ground Water Extraction. The extraction method for this ground water alternative would be identical to the extraction method described for Alternative 3B (see Section 4.2.4.4, Ground Water Extraction). Figure 4.2.4-1 presents the extraction well locations and the predicted ground water capture zone when the extraction wells are operating. Intermediate (15 years) and final (10 years) contour maps are presented in Figures 4.2.4-2 to 4.2.4-5. These figures, along with the capture zone, demonstrate that this alterative will remediate the site and capture the reinfiltrated ground water.

4.2.6.5 Equalization. The equalization method for this ground water alternative would be identical to the equalization method described for Alternative 3B (see Section 4.2.4.5, Equalization). The extracted ground water would be pumped to a 18,000-gallon equalization tank that would provide an approximately 50-minute retention time.

4.2.6.6 GAC Primary Treatment. The GAC treatment method for this ground water alternative would be identical to the GAC treatment method described for Alternative 4A (see Section 4.2.5.6, GAC Primary Treatment), except that the volume of GAC required on a daily basis for the operation of the treatment system at the flow rate for this alternative would be approximately 310 pounds GAC per day (see Appendix C). Therefore, each carbon bed would last approximately 6.5 days before being removed for incineration.

4.2.6.7 Reinfiltration. For approximately the first two months, 200 gpm will be infiltrated into the washout lagoons to flush the soils. The additional 133 gpm will be pumped to the reinfiltration galleys upgradient of the washout lagoons. After six months all 333 gpm will be sent to the reinfiltration galleys. The reinfiltration method for this alternative would consist of a slightly larger reinfiltration galley, approximately 5,326 square feet, but would otherwise be identical to the system described for Alternative 3A (see Section 4.2.3.7, Reinfiltration). A description of this process will not be repeated here.

4.2.6.8 Capital Cost. The capital cost for the GAC treatment system is approximately $0.55 million, as presented in Table 4.2.6-1. The capital cost for the GAC system is spread out fairly evenly between all the unit operations. A moderate increase in the flow rate or the concentration of contaminants in the inlet would not require a larger GAC system. The capital cost would also be increased if the number of extraction wells needed to be increased to ensure that the capture zone was maintained; if the number of wells was doubled the total capital cost would only be increased by approximately $175,000.

4.2.6.9 Operating Cost. The annual operating cost for the GAC treatment system is approximately $0.7 million, as presented in Table 4.2.6-2. Using the annual operating cost, the NPV was calculated for the 10 year scenario using a 5% and a 10% interest rate.

Table 4.2.6-1: Capital Cost for Granular Activated Carbon – Alternative 4B

Item No.	Item	Units	Unit Cost (1993 $)	# of Units	Total Cost (1993 $)
100	**Extraction**				
101	GW Wells - 8 inch, 155 feet	Well	30,000	3	90,000
102	GW Well Pumps - 250 gpm, 7.5 hp	Pump	2,550	3	7,650
103	GW Buried Pipeline	Pipeline/500 ft	4,250	6	25,500
200	**Equalization**				
201	Equalization/Settling - 18,000 gal	Tank	50,800	1	50,800
202	Feed Pump - 350 gpm, 7 hp	Pump	2,800	2	5,600
300	**Granular Activated Carbon**				
301	GAC Tank - 2000 gal	Tank	4,250	2	8,500
302	GAC - 2000 lb	Bed	4,500	2	9,000
303	Discharge Pump - 350 gpm, 8 hp	Pump	2,900	2	5,800
400	**Reinfiltration Galley**				
401	Excavation	C.Y.	2	2,177	4,898
402	Crushed Stone	C.Y.	19	725	13,848
403	Backfill	C.Y.	2	217	365
404	Infiltration Galley	Galley	200	333	66,600
500	**Lagoon Lining**				
501	HDPE Lining	Lagoon	3,000	2	6,000
502	Crushed Stone	C.Y.	19	520	9,932
Equipment Subtotal					**$304,492**
Remedial Design / Planning		10 % of Purchased Equipment Cost			30,449
Plumbing		10 % of Purchased Equipment Cost			30,449
Electrical		10 % of Purchased Equipment Cost			30,449
Instrumentation and Controls		10 % of Purchased Equipment Cost			30,449
Construction and Installation		30 % of Purchased Equipment Cost			91,348
Treatment System Building		sq feet	27	1,200	32,400
Installation Subtotal					**$245,545**
Total Capital Cost					**$550,037**

Source: Arthur D. Little, Inc.

Table 4.2.6-2: Annual Operating Cost for Granular Activated Carbon - Alternative 4B

Item	Units	Units/ Year	Unit Cost (1993 Dollars)	Annual Cost (1993 Dollars)
Variable Cost				
Monitoring				
Sample Collection	hours	640	30	19,200
Supervision	hours	32	50	1,600
Sample Analysis	samples	152	150	22,800
Data Review and Reporting	hours	32	65	2,080
Five-Year Review (a)	hours	50	80	4,000
Electrical (b)	kw/yr	615,120	0.06	36,907
Granular Activated Carbon				
GAC Bed - 2000 lbs	Ton	56.5	4500	254,250
GAC Incineration (c)				
Polyethylene Lined Drums	Drum	337	25	8,425
Shipping	Drum	337	125	42,125
Treatment/Disposal	Drum	337	420	141,540
Operational Monitoring	samples	100	150	15,000
Labor				
Operator (d)	hours	2,500	30	75,000
Supervisor (e)	hours	200	50	10,000
Variable Cost Subtotal				$632,927
Fixed Cost				
Maintenance				
Labor and Materials	7% of Capital Investment			38,500
Fixed Cost Subtotal				$38,500
Total Annual Operating Cost				$671,427

Notes:
(a) – The cost for the Five-Year Review has been divided evenly over five years
(b) – Electrical includes power for pumps, and misc. electrical
for heating building, lighting, etc.
(c) - Assumes 335 pounds of GAC/55 gallon drum
(d) – Two operators on-site 3.0 days/week
(e) – One supervisor 4 hours/week to review operation of process

Source: Arthur D. Little, Inc.

		5% Interest Rate		10% Interest Rate	
Time Frame	Annual Cost	Discount Factor	NPV	Discount Factor	NPV
1-10 years	$0.7M	7.9	$5.5M	6.0	$4.2M

The carbon purchase and carbon disposal represent the largest operating costs for this alternative. If the flow rate or the contaminant concentration in the inlet to the GAC system was increased by 50% carbon usage would also increase by 50%. This increase in carbon usage would increase the operating costs from $670,000 to $880,000, and the 5% NPV would increase from $5.5 million to $7.2 million.

4.2.6.10 NCP Evaluation Criteria. The degree to which GAC treatment of the contaminated ground water meets the NCP evaluation criteria is discussed below.

Overall Protection of Human Health and the Environment

This alternative would return the ground water to its potential beneficial use within 10 years. Upon achieving the remedial action objectives, the total hazard index for the ingestion of ground water for all compounds, at reasonable maximum exposure, would be reduced from 60 to 2.0. The total incremental cancer risk for the ingestion of ground water for all compounds at reasonable maximum exposure would be reduced from $2x10^{-3}$ to $1.3x10^{-5}$ (see Section 2.1, Remedial Action Objectives).

Unlike the UV/oxidation alternatives this alternative would not provide treatment for the contamination on site. The spent GAC would be sent off site for thermal destruction. The alternative would not pose a short-term risk to human health or the environment and would maximize the amount of water that was returned to the aquifer.

Compliance with ARARs

The alternative would meet the preliminary remediation goals in 10 years. The alternative would meet all action-specific ARARs, including:

- No state and federal safe drinking water regulations exist for the contaminants of concern; therefore, the extracted ground water will be treated to ensure that each compound meets a hazard index equal to or less than 1, an excess cancer risk of greater than 10^{-6}, or the compound's detection limit prior to its return to the aquifer.

- State surface water discharge or underground injection regulations on the disposal of the treated ground water.

- All RCRA requirements will be met in regard to the transport and disposal of the residuals from the treatment process. The exposure concentration in the spent carbon will be equal to or less than 7%, which is well below the explosive limit of 10% (Arthur D. Little, 1987). A TCLP analysis of the spent GAC would have to be performed to ensure that the DNT concentration is below the RCRA limit.

Long-Term Effectiveness

The residual risk that would remain on site due to contamination in the ground water would be reduced to a hazard index of 2 and a carcinogenic risk of 1.3×10^{-5} in 10 years. Without active contamination treatment, the risk reduction would not be reached for 5,000 years.

Treatment residuals that are generated during the remediation of the ground water would be disposed of in a manner to eliminate unacceptable risks. The contaminants would be adsorbed onto the GAC, which would then be destroyed at a permitted off-site incinerator or by another type of thermal treatment (e.g., regeneration or a cement kiln). Any solids removed from the equalization tank would be shipped off site for treatment and disposal.

The alternative would be operated until the ground water met the stated cleanup levels for the alternative, and the contaminants would be destroyed when the carbon is incinerated or by another type of thermal treatment (e.g., regeneration or a cement kiln). Therefore, no long-term controls would be necessary. The technologies that would be used in this alternative are considered to be reliable and have been proven at other similar sites.

This alternative would require five-year reviews to evaluate whether the alternative is protective of public health and the environment. The five-year reviews would be initiated five years after the start of the remedial action and would continue until no contaminants remain at the site above levels that allow for unrestricted use and unlimited exposure.

Reduction of Toxicity, Mobility, or Volume Through Treatment

The contaminants would be treated using the GAC system; any contamination adsorbed on the GAC will be irreversibly destroyed by incineration of the carbon or by another type of thermal treatment (e.g., regeneration or a cement kiln). This treatment system will reduce the volume, toxicity, and mobility of the contaminants.

The primary GAC treatment system will generate approximately 57 tons/year of spent carbon for off-site incineration. In addition to the spent GAC, an estimated 200 pounds of sediment will be collected each year in the equalization tank; this material will be analyzed and disposed of on site if found to be free of contamination.

Short-Term Effectiveness

The operation of the GAC treatment system is not expected to increase the risk to the community or the environment because the contaminants will be adsorbed on the GAC and incinerated. The risks to the workers and the environment from accumulation of explosive levels of contaminants on the GAC would be minimized through the operational restriction on carbon loading, as well as the use of engineering controls and personal protective equipment. The alternative would meet the remedial action objectives within 10 years. If no active remediation alternative is implemented at the site, the ground water will not meet the remedial action objectives for an estimated 5,000 years.

Implementation

The construction and operation of the GAC treatment system can be easily implemented and is technically capable of treating the contaminants in the ground water. The capacity of the GAC system can be increased if additional ground water needs to be treated or the concentration of contamination is greater than expected. The design of the treatment system will also facilitate system scale-down as the contaminant loading decreases over the life of the project.

There is some uncertainty surrounding the reinfiltration of treated ground water into the lagoons to flush the remaining contaminants from the soils. Because there is the potential for the reinfiltration spreading the contamination, the ground water in the vicinity of the lagoons will have to be monitored to ensure that reinfiltration is not adversely affecting the ability to remediate the ground water. If there is a concern, then the ground water will be switched to the reinfiltration galleys upgradient.

No special equipment, materials, or technical specialists would be required for the implementation of the system. Vendors are also currently available for the supply and incineration of the GAC.

State and local coordination would be required for the implementation of legal restrictions on the use of ground water at the site and the discharge of treated ground water to the environment.

Cost

The capital and operating costs are presented in Section 4.2.6.8 and Section 4.2.6.9, respectively.

4.2.7 Alternative 5A - UV/Oxidation (30 Years, Remediated to a Carcinogenic Risk of 1×10^{-4} and a Hazard Index of 1)

In this alternative, the ground water will be extracted from a series of 3 wells over a 30-year period to remediate the ground water to 77 µg/L for RDX and 18 µg/L for TNT (risk-based cleanup level at 1×10^{-4} and a hazard index of 1, respectively). The ground water will be treated by hydroxide precipitation to remove the background metals from the contaminated ground water and then treated by UV/oxidation to destroy the explosives (see Figure 4.2.3-1). The results of a recent treatability study conducted at the Milan Army Ammunition Plant (ICF Kaiser Engineers, 1993), which has a ground water contaminant chemistry similar to that at Umatilla, indicate that it is not economically feasible to utilize UV/oxidation for complete contaminant destruction. Therefore, granular activated carbon (GAC) with off-site incineration of the spent carbon will be included as a polishing step to the primary UV/oxidation treatment.

After the ground water has been treated to meet all risk-based cleanup levels, it will initially be pumped to the explosive washout lagoons, where it will be allowed to reinfiltrate into the soils under the lagoons. Reinfiltration of the treated ground water into the lagoons will flush the remaining soil contamination into the ground water table, where it will be collected downgradient in the extraction wells. After approximately 15 months the reinfiltration of the treated ground water will be moved to infiltration galleys 400 to 800 feet upgradient of the lagoons.

In addition, this alternative will require ground water monitoring, five-year reviews, and institutional controls, which will continue until the contamination has been remediated to the detection limits stated above.

4.2.7.1 Institutional Controls. While the ground water is being remediated, institutional controls will be needed to restrict access to the contaminated aquifer, the contaminated ground water remediation equipment and the interconnecting piping. The level of institutional controls is similar to that previously discussed in Section 4.2.2, Alternative 2, and will not be repeated here.

4.2.7.2 Monitoring. The monitoring program would sample the existing monitoring wells and is identical to the program presented in Section 4.2.2.2, Monitoring, for the Institution Control Alternative.

4.2.7.3 Five-Year Reviews. In addition to the monitoring of the ground water and the institutional controls, this alternative would also require five-year reviews intended to evaluate whether the alternative remains protective of public health and the environment. The five-year reviews would be initiated five years after the start of the remedial action and continue until no contaminants remain at the site above levels that allow for unrestricted use and unlimited exposure. These reviews would be identical to the reviews described for the No Action alternative (see the introduction to Section 4.2, Individual Analysis of Alternatives).

4.2.7.4 Ground Water Extraction. The extraction method for this ground water alternative would be identical to the extraction method described for Alternative 3A (see Section 4.2.3.4, Ground Water Extraction), except that the total pumping rate would be 78 gallons per minute (gpm). Figure 4.2.7-1 presents the extraction well locations and the predicted ground water capture zone when the extraction wells are operating. Intermediate (15 years) and final (30 years) contour maps are presented in Figures 4.2.7-2 and 4.2.7-5. These figures, along with the capture zone, demonstrate that this alternative will remediate the site and capture the reinfiltrated ground water.

4.2.7.5 Equalization. The equalization method for this ground water alternative would be identical to the equalization method described for Alternative 3A (see Section 4.2.3.5, Equalization), except that extracted ground water would be pumped to a 3,500-gallon equalization tank that would provide an approximately 50-minute retention time.

4.2.7.6 Ultraviolet/Oxidation.

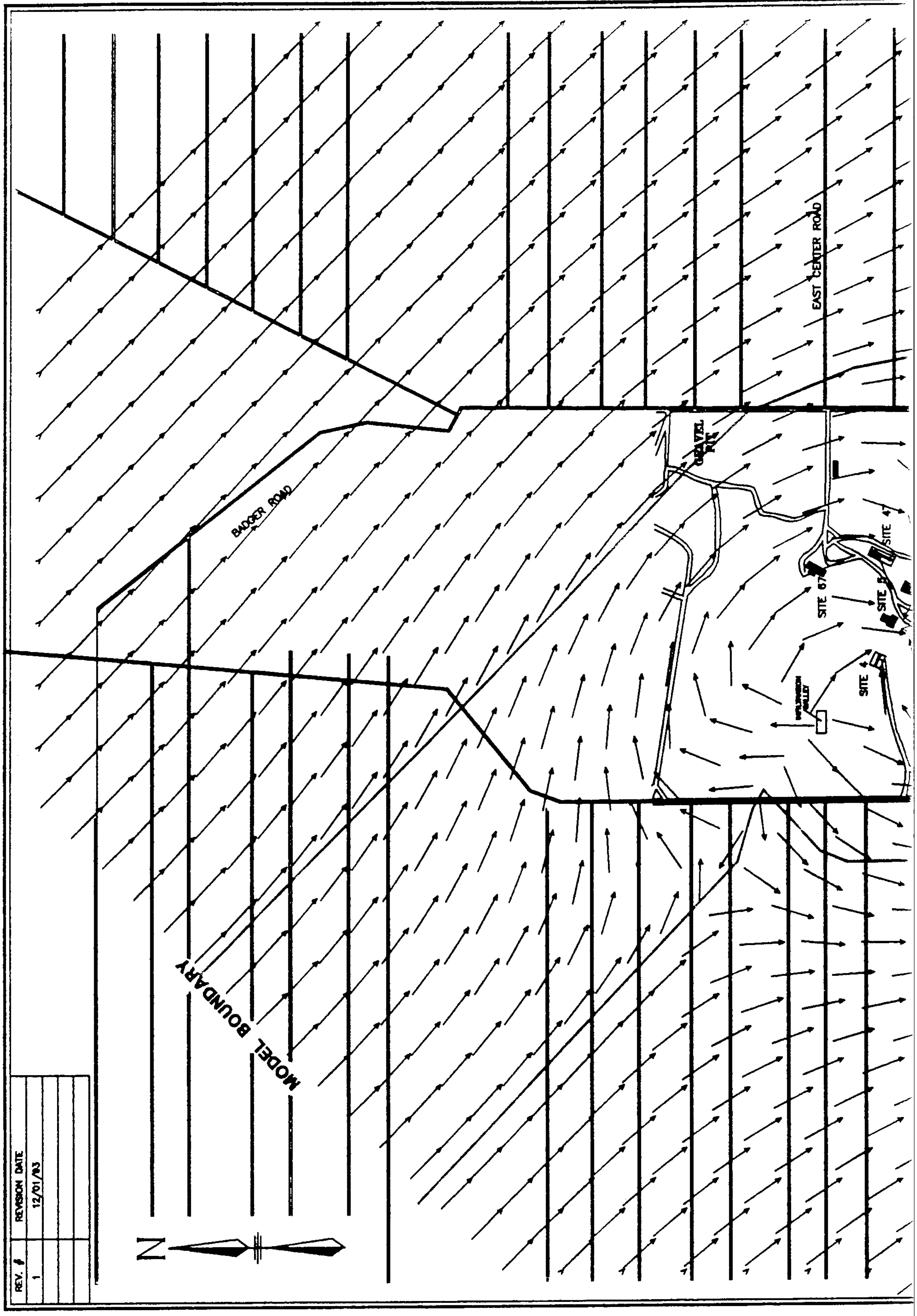
4.2.7.6.1 Metal Precipitation. The metal precipitation method for this ground water alternative would be identical to the metal precipitation method described for Alternative 3A (see Section 4.2.3.6.1, Metal Precipitation), except that operating parameters, and where appropriate the volume of material required on a daily basis, for the operation of such a metal precipitation system at the flow rate for this alternative would be:

Parameter	Operating Condition
$KMnO_4$ Dose	40 mg/L (15 kg/day)
Operating pH	11.0 units
NaOH Dose	400 mg/L (148 kg/day 50% NaOH)
Anionic Polymer Dose	3 mg/L (1.2 kg/day)
H_2SO_4 Dose	490 mg/L (182 kg/day 50% H_2SO_4)
Sludge Production	0.29 tons/day (@ 30% solids)

4.2.7.6.2 UV/Oxidation. The Ultraviolet/oxidation method for this alternative would be identical to the method described in Section 4.2.3.6.2, UV/Oxidation, and will not be repeated here.

4.2.7.6.3 GAC Polishing. The carbon polishing system for this option would be identical to that described in Section 4.2.3.6.3, GAC Polishing, except that the carbon use rate was calculated to be 7.2 pounds carbon/day. Therefore, each carbon bed would last approximately 281 days before being removed for incineration or another type of thermal treatment.

4.2.7.7 Reinfiltration. For approximately the first 15 months, treated ground water will be infiltrated into the washout lagoons to flush the soils. The reinfiltration method for this alternative would consist of a slightly smaller reinfiltration galley,


EAST CENTER ROAD
GRAVEL PIT
BADGER ROAD
SITE 47
SITE 67
SITE 5
SITE 4
INFILTRATION GALLERY
MODEL BOUNDARY
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REV. #
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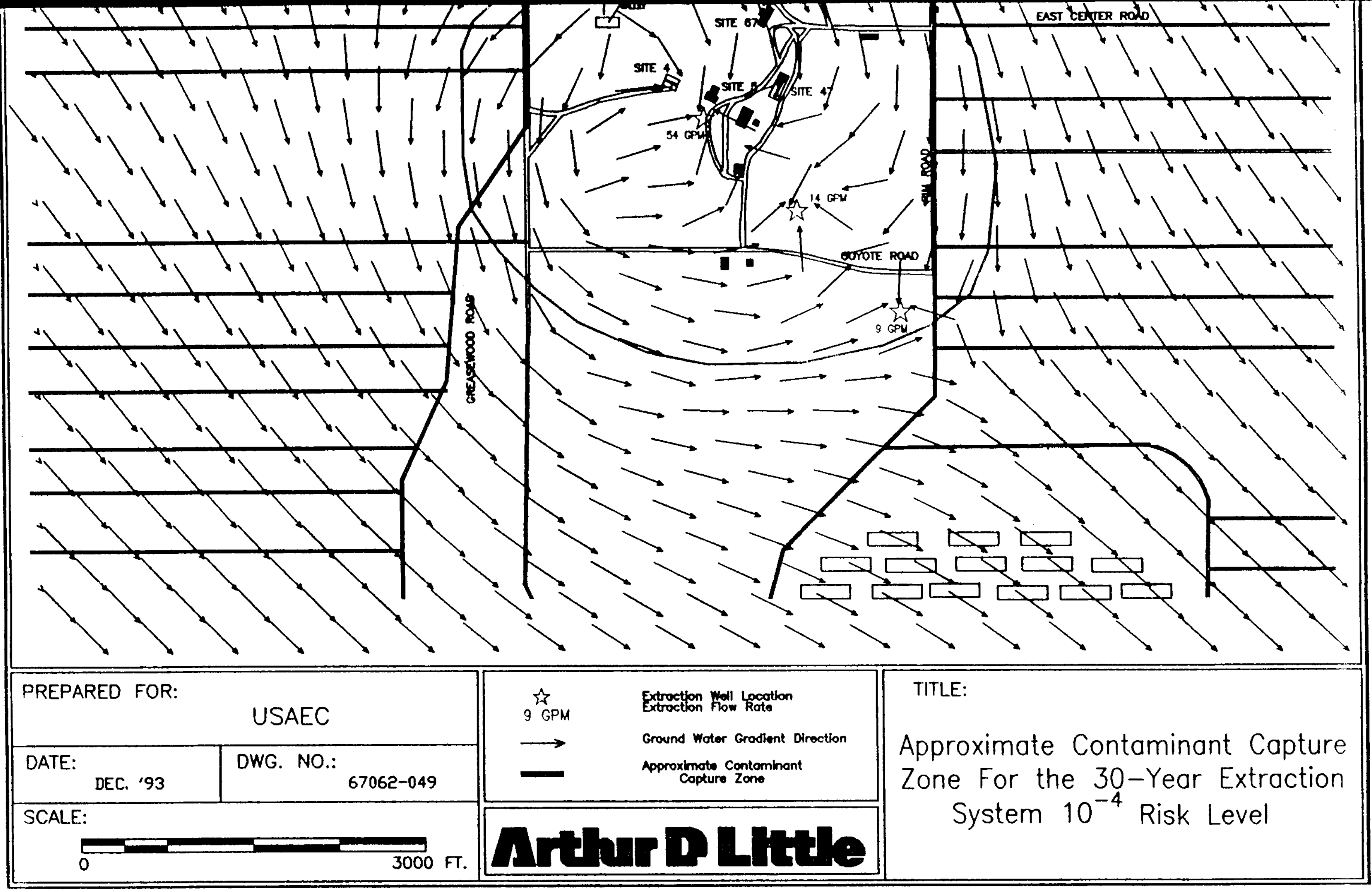

EAST CENTER ROAD
SITE 67
SITE 4
SITE 8
SITE 47
54 GPM
14 GPM
9 GPM
RIM ROAD
COYOTE ROAD
GREASEWOOD ROAD
9 GPM
Extraction Well Location
Extraction Flow Rate
Ground Water Gradient Direction
Approximate Contaminant Capture Zone
0
3000 FT.
Arthur D Little

PREPARED FOR:
USAEC

DATE:
DEC. '93

DWG. NO.:
67062-049

SCALE:

TITLE:
Approximate Contaminant Capture Zone For the 30–Year Extraction System 10^{-4} Risk Level

Figure 4.2.7-1: Approximate Contaminant Capture Zone for the 30-Year Extraction System 10^{-4} Risk Level

REV. #	REVISION DATE
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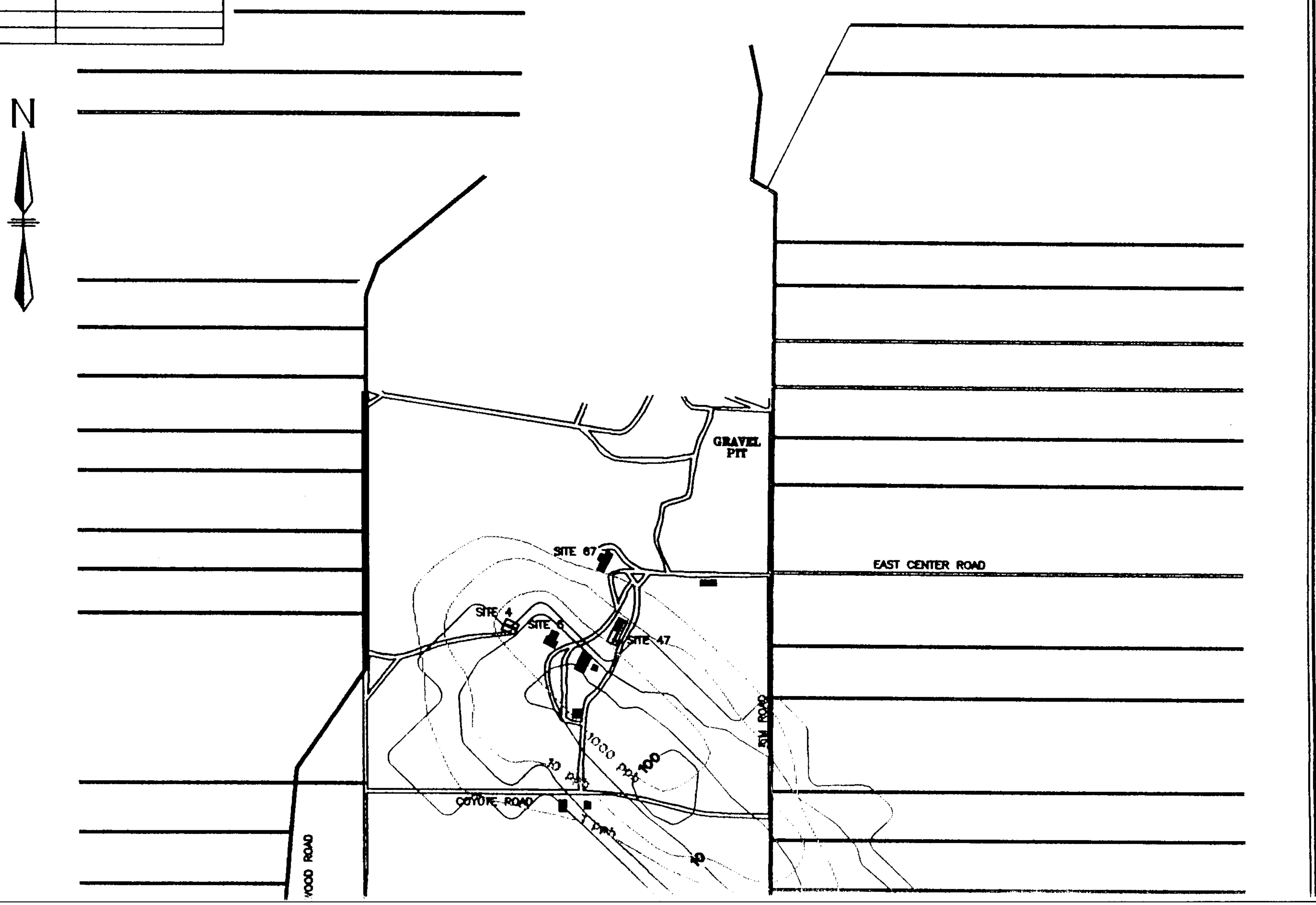
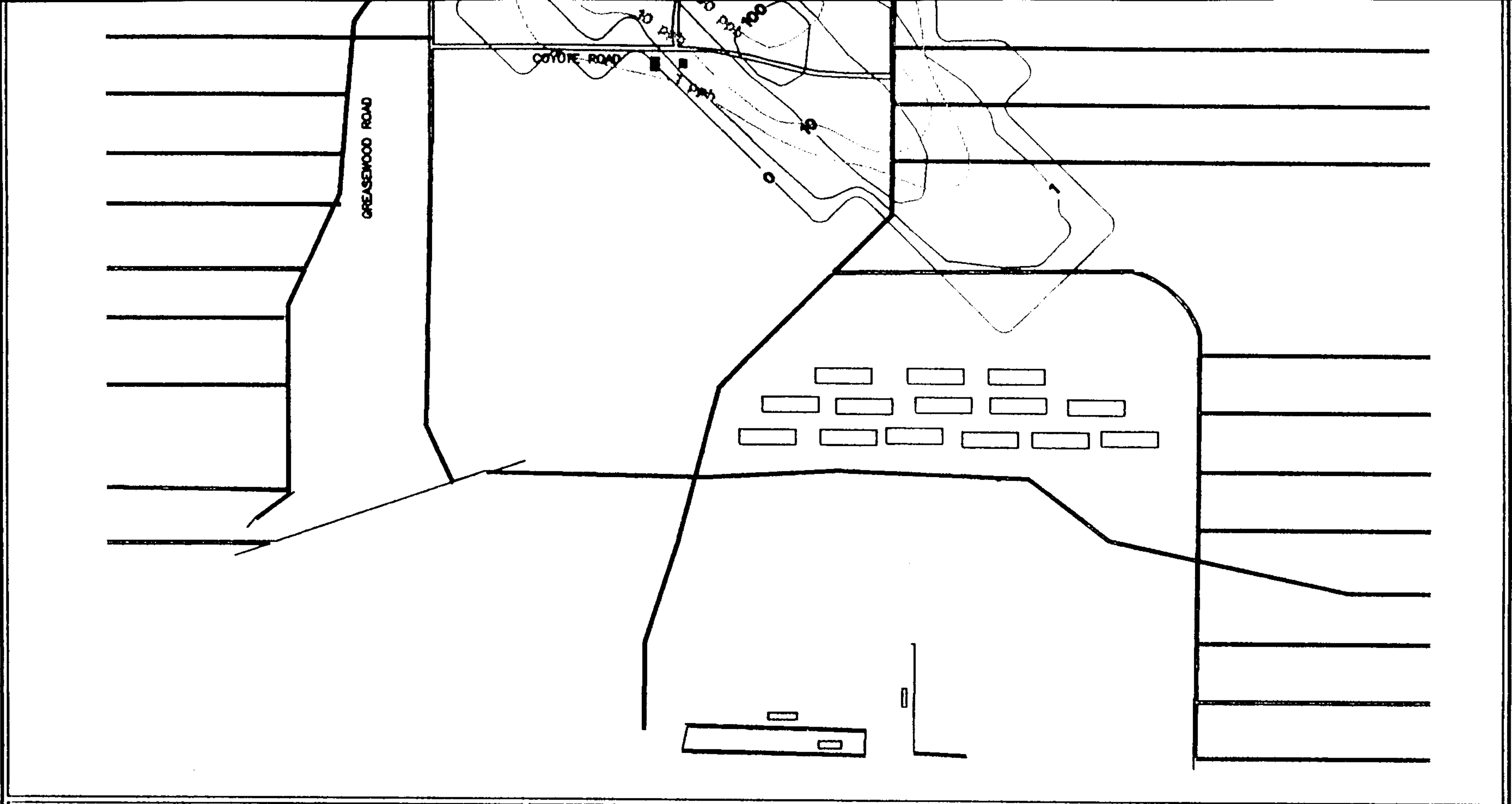

N
GRAVEL PIT
EAST CENTER ROAD
SITE 67
SITE 4
SITE 6
SITE 47
5TH ROAD
1000 ppb
100
10 ppb
COYOTE ROAD
1 ppb
10
WOOD ROAD


GREASEWOOD ROAD
COYOTE ROAD
10 ppb
100
1 ppb
10
0
1

PREPARED FOR: USAEC

DATE: DEC. '93

DWG. NO.: 67062-060

SCALE: 0 — 3000 FT.

—— Simulated RDX Concentrations after 15 years (ppb)

······ Simulated Current RDX Concentrations (ppb)

Source: Arthur D. Little, Inc.

Arthur D Little

TITLE:

Simulated RDX Concentrations after 15 years with a Remediation Objective of an Incremental Risk of 1 x 10^{-4} and a Hazard Index of 1

Figure 4.2.7-2: Simulated RDX Concentrations After 15 Years

2 of 2

REV. #	REVISION DATE
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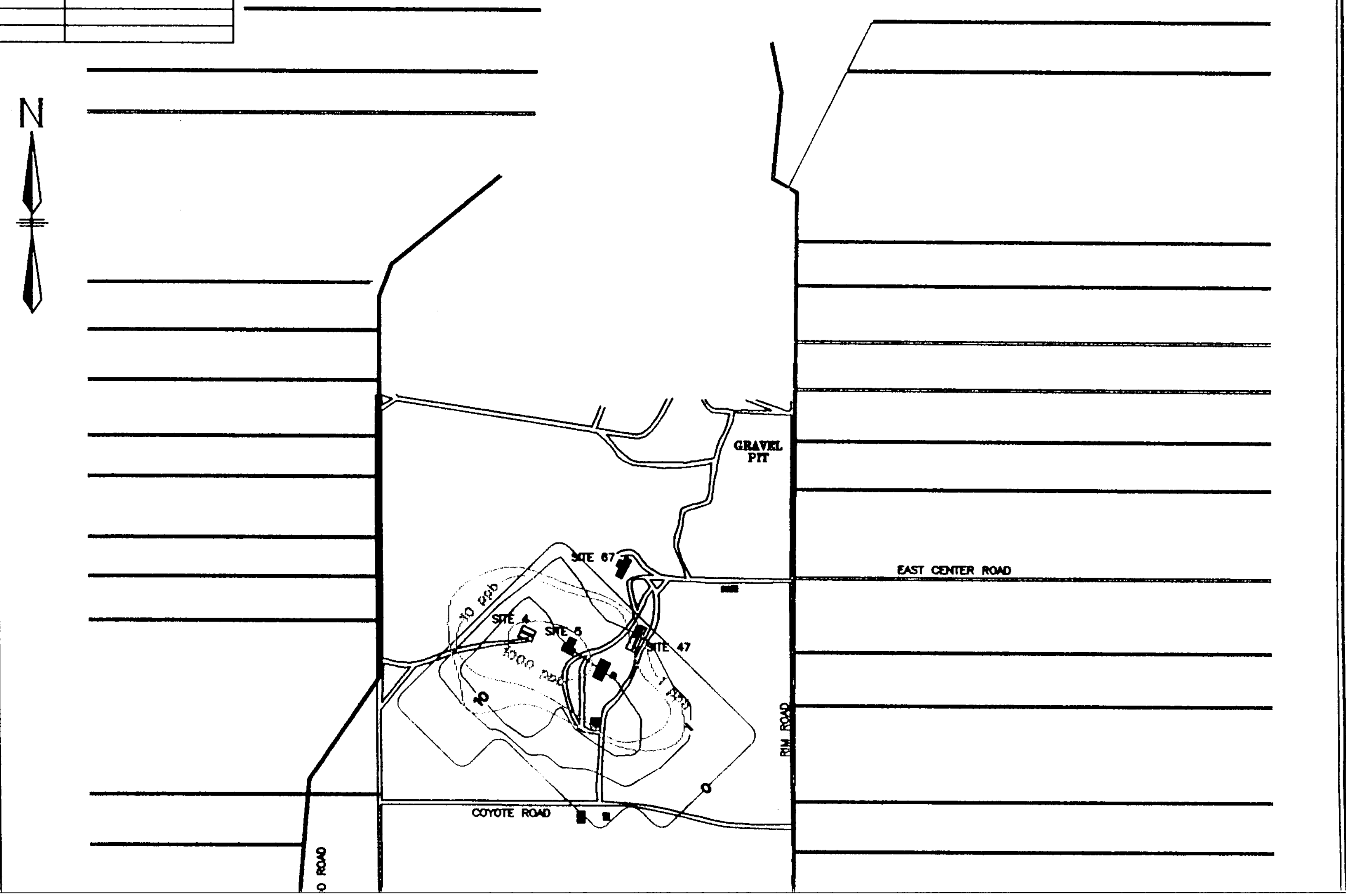
N
GRAVEL PIT
EAST CENTER ROAD
SITE 67
SITE 4
SITE 5
SITE 47
10 ppb
1000 ppb
1 ppm
10
0
RIM ROAD
COYOTE ROAD
O ROAD

102

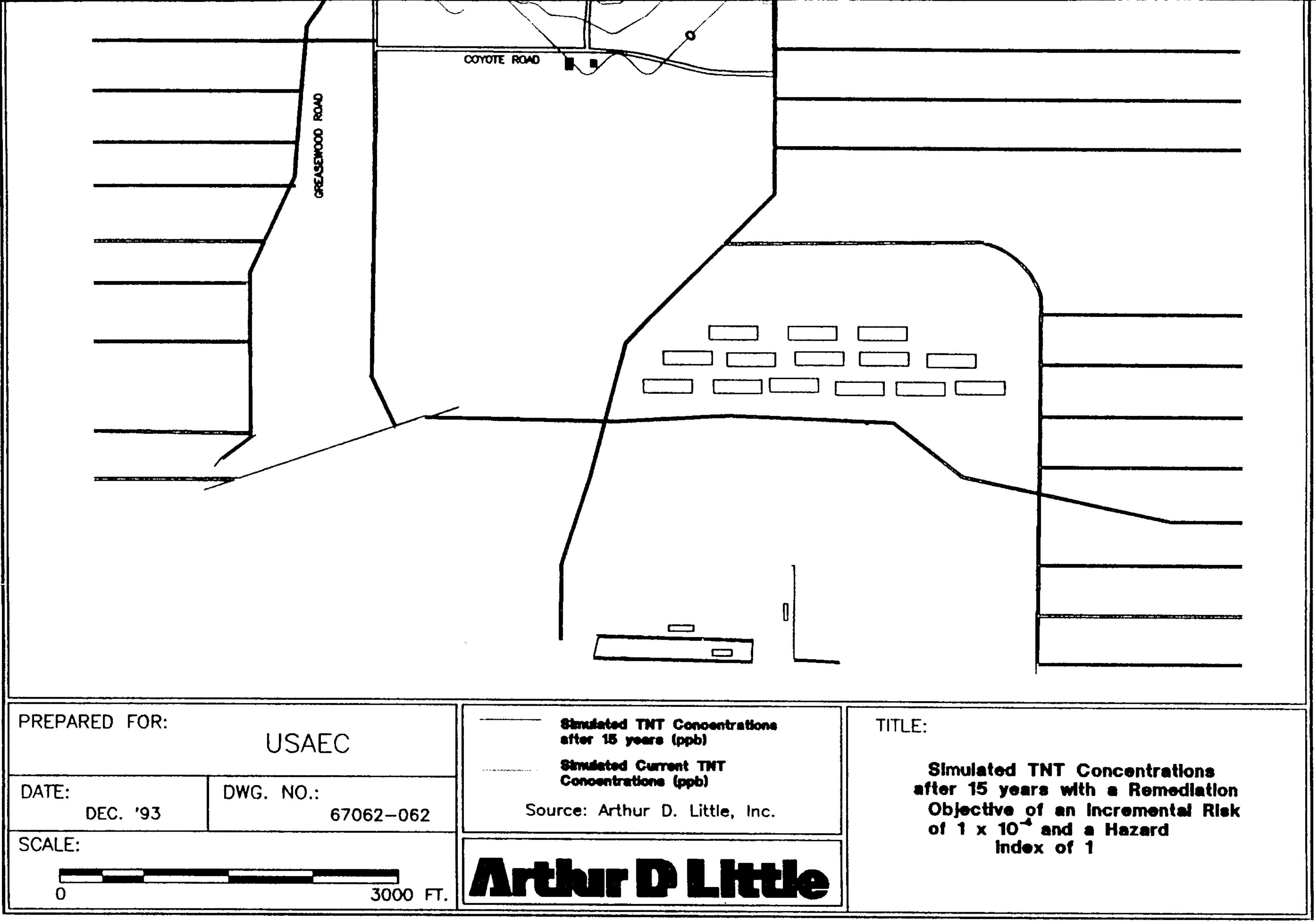
COYOTE ROAD
GREASEWOOD ROAD
PREPARED FOR:
USAEC
DATE:
DEC. '93
DWG. NO.:
67062-062
SCALE:
0
3000 FT.
Simulated TNT Concentrations after 15 years (ppb)
Simulated Current TNT Concentrations (ppb)
Source: Arthur D. Little, Inc.
Arthur D Little
TITLE:
Simulated TNT Concentrations after 15 years with a Remediation Objective of an Incremental Risk of 1 x 10-4 and a Hazard Index of 1

Figure 4.2.7-3: Simulated TNT Concentrations After 15 Years

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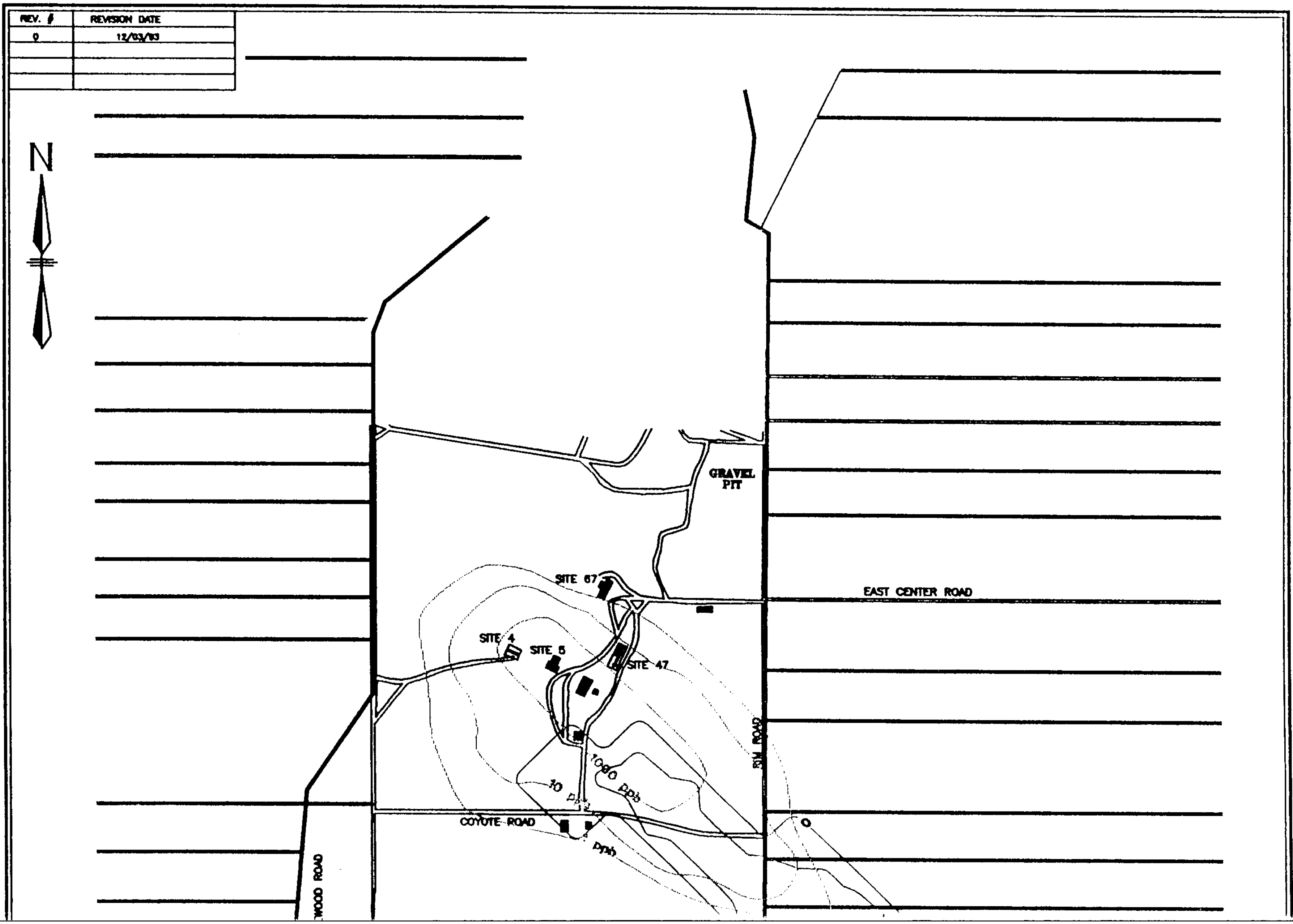
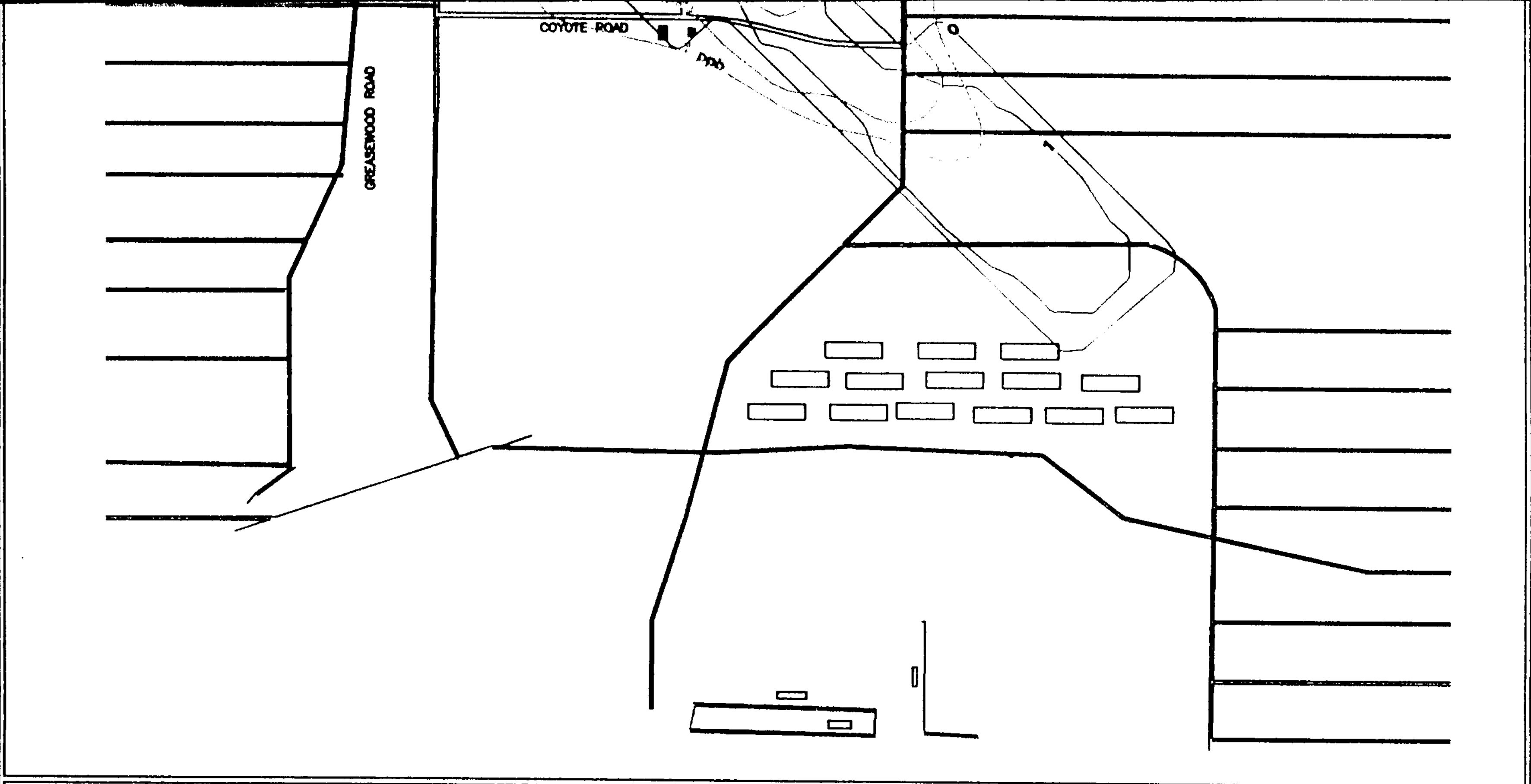

N
GRAVEL PIT
EAST CENTER ROAD
SITE 67
SITE 4
SITE 5
SITE 47
RIM ROAD
1000 ppb
10 ppb
ppb
0
COYOTE ROAD
WOOD ROAD



PREPARED FOR:
USAEC

DATE:
DEC. '93

DWG. NO.:
67062–059

SCALE:
0
3000 FT.

——— **Simulated RDX Concentrations after 30 years (ppb)**

┈┈┈ **Simulated Current RDX Concentrations (ppb)**

Source: Arthur D. Little, Inc.

Arthur D Little

TITLE:

Simulated RDX Concentrations after 30 years with a Remediation Objective of an Incremental Risk of 1 x 10^{-4} and a Hazard Index of 1

Figure 4.2.7-4: Simulated RDX Concentrations After 30 Years

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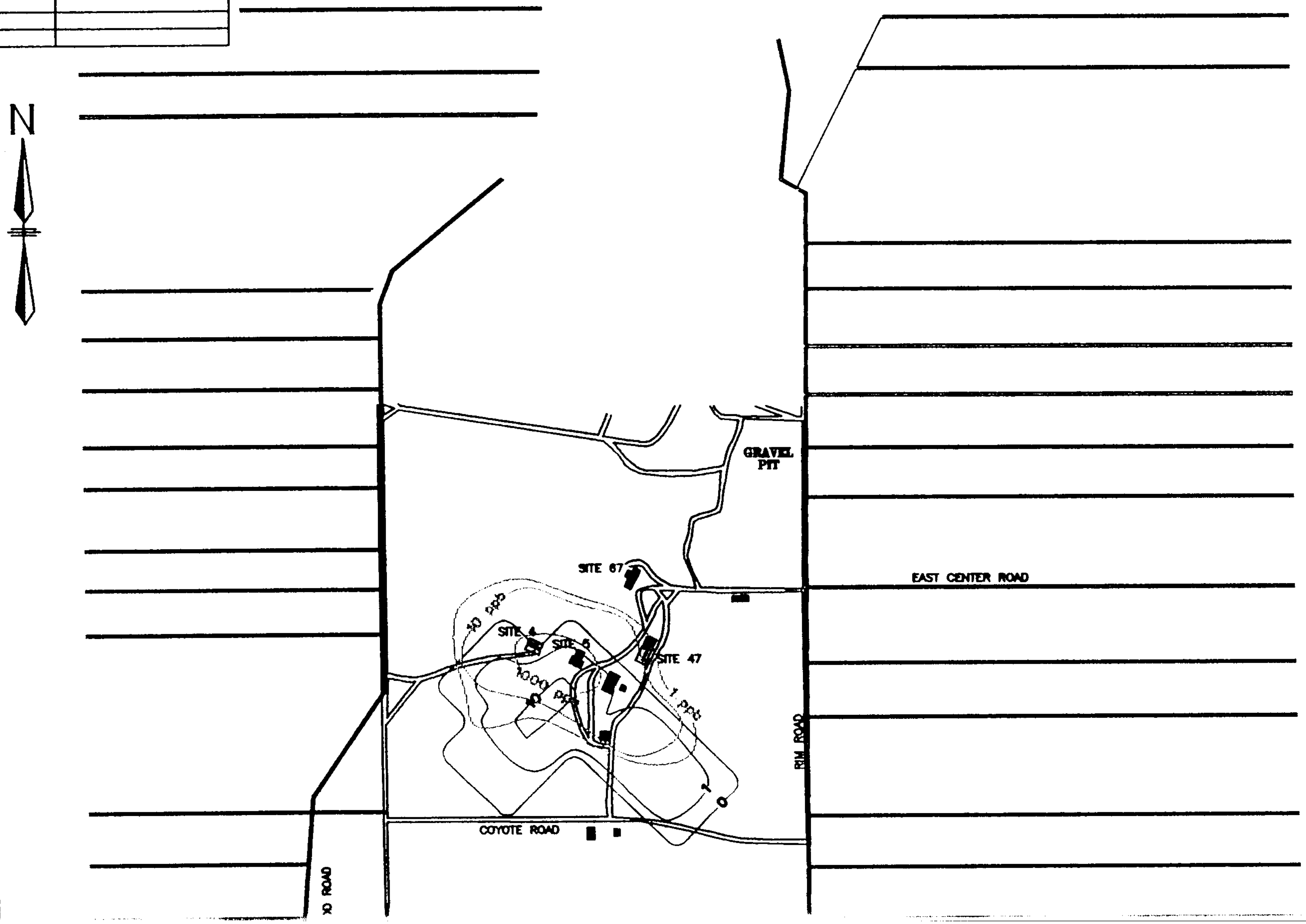
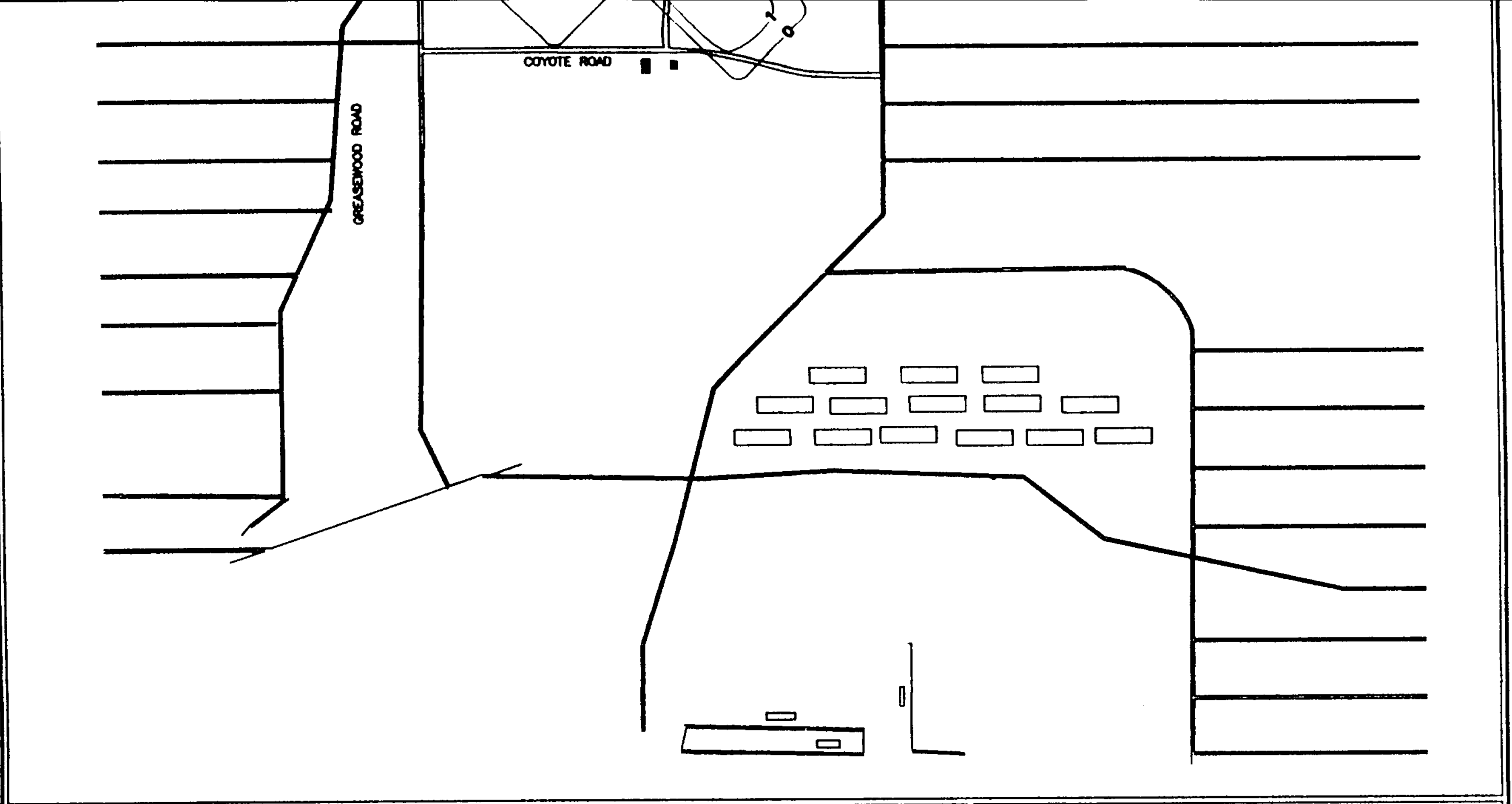

N
GRAVEL PIT
SITE 67
EAST CENTER ROAD
10 ppb
SITE 4
SITE 5
SITE 47
1000 ppb
1 ppb
RIM ROAD
0
COYOTE ROAD
XO ROAD

182



PREPARED FOR: USAEC

DATE: DEC. '93

DWG. NO.: 67062-061

SCALE: 0 3000 FT.

Simulated TNT Concentrations after 30 years (ppb)

Simulated Current TNT Concentrations (ppb)

Source: Arthur D. Little, Inc.

Arthur D Little

TITLE:

Simulated TNT Concentrations after 30 years with a Remediation Objective of an Incremental Risk of 1 x 10^{-4} and a Hazard Index of 1

Figure 4.2.7-5: Simulated TNT Concentrations After 30 Years

2-72

approximately 1,090 square feet, but would otherwise be identical to the method described for Alternative 3A (see Section 4.2.3.7, Reinfiltration). A description of this process will not be repeated here.

4.2.7.8 Capital Cost. The capital cost for the UV/oxidation system is approximately \$1.7 million, as presented in Table 4.2.7-1. The capital cost of this alternative is strongly dependent on the cost of the UV/oxidation system, which is approximately 50% of the overall capital cost. The cost of the UV/oxidation system would be increased if the volume of water to be treated increased or the retention time to reach the preliminary remedial goals increased. If the water volume to the UV system was increased or the retention time was increased by 50% the capital cost would be increased from \$1.7 million to \$2.2 million. The capital cost would also be increased if the number of extraction wells needed to be increased to ensure that the capture zone was maintained; if the number of wells was doubled the total capital cost would only be increased by approximately \$175,000.

4.2.7.9 Operating Cost. The annual operating cost for the UV/oxidation system is approximately \$0.6 million, as presented in Table 4.2.7-2. Using the annual operating cost, the NPV was calculated for the 30-year scenario using a 5% and a 10% interest rate.

		5% Interest Rate		10% Interest Rate	
Time Frame	**Annual Cost**	**Discount Factor**	**NPV**	**Discount Factor**	**NPV**
1-30 years	\$0.6M	15.8	\$9.5M	9.9	\$5.9M

The operating cost for this alternative is strongly dependent on the electrical cost for the operation of the UV/oxidation system. The electrical cost would increase if the size of the UV/oxidation system was increased. A 50% increase in the size of the UV/oxidation system would increase the electrical costs from \$216,000 to \$432,000, and the 5% NPV would increase from \$9.5 million to \$12.3 million.

4.2.7.10 NCP Evaluation Criteria. The degree to which UV/oxidation of the contaminated ground water meets the NCP evaluation criteria is discussed below.

Overall Protection of Human Health and the Environment

This alternative would return the ground water to its beneficial use within 30 years. Upon achieving the remedial action objectives, the total hazard index for the ingestion of ground water for all compounds, at reasonable maximum exposure, would be reduced from 60 to 2. The total incremental cancer risk for the ingestion of ground water for all compounds at reasonable maximum exposure would be reduced from $2x10^{-3}$ to 3×10^{-4} (see Section 2.1, Remedial Action Objectives).

Table 4.2.7-1: Capital Cost for Ultraviolet/Oxidation – Alternative 5A

Item No.	Item	Units	Unit Cost (1993 $)	# of Units	Total Cost (1993 $)
100	**Extraction**				
101	GW Wells - 8 inch, 155 feet	Well	30,000	3	90,000
102	GW Well Pumps - 70 gpm, 2.5 hp	Pump	1,375	3	4,125
103	GW Buried Pipeline	Pipeline/500 ft	4,250	6	25,500
200	**Equalization**				
201	Equalization/Settling - 3,500 gal	Tank	8,160	1	8,160
202	Feed Pump - 100 gpm, 2 hp	Pump	1,500	2	3,000
300	**Metal Precipitation**	System	131,200	1	131,200
301	pH Control System				
302	Oxidant Addition Pump				
303	Treatment Tank with Mixer				
304	Polymer Feed System				
305	Clarification System				
306	Sludge Thickening System				
307	Filter Press				
308	Multi-Media Filter				
400	**UV/Oxidation**	System	658,000	1	658,000
401	UV Reactor				
402	UV Feed Pump				
403	Ozone Generation and Destruction				
500	**Granular Activated Carbon**				
501	GAC Tank - 2000 gal	Tank	4,250	2	8,500
502	GAC - 2000 lb	Bed	4,500	2	9,000
503	Discharge Pump - 100 gpm, 3 hp	Pump	1,600	2	3,200
600	**Reinfiltration Galley**				
601	Excavation	C.Y.	2	442	995
602	Crushed Stone	C.Y.	19	147	2,808
603	Backfill	C.Y.	2	44	74
604	Infiltration Galley	Galley	200	69	13,800
700	**Lagoon Lining**				
701	HDPE Liner	Lagoon	3,000	2	6,000
702	Crushed Stone	C.Y.	19	520	9,932
Equipment Subtotal					**$974,293**
Remedial Design / Planning		10 % of Purchased Equipment Cost			97,429
Plumbing		10 % of Purchased Equipment Cost			97,429
Electrical		10 % of Purchased Equipment Cost			97,429
Instrumentation and Controls		10 % of Purchased Equipment Cost			97,429
Construction and Installation		30 % of Purchased Equipment Cost			292,288
Treatment System Building		sq feet	27	1,200	32,400
Installation Subtotal					**$714,405**
Total Capital Cost					**$1,688,698**

Source: Arthur D. Little, Inc.

Table 4.2.7-2: Annual Operating Cost for Ultraviolet/Oxidation - Alternative 5A

Item	Units	Units/ Year	Unit Cost (1993 Dollars)	Annual Cost (1993 Dollars)
Variable Cost				
Monitoring				
Sample Collection	hours	640	30	19,200
Supervision	hours	32	50	1,600
Sample Analysis	samples	152	150	22,800
Data Review and Reporting	hours	32	65	2,080
Five -Year Review (a)	hours	50	80	4,000
Metals Precipitation (b)	1000 gal (c)	40,997	0.4	16,399
Electrical (d)	kw/yr	3,600,000	0.06	216,000
Ozone	1000 gal (c)	40,997	0.25	10,249
Granular Activated Carbon				
GAC Bed - 2000 lbs	ton	1.3	4500	5,850
GAC Incineration (e)				
Polyethylene Lined Drums	drum	7.8	25	195
Shipping	drum	7.8	125	975
Treatment/Disposal	drum	7.8	420	3,276
Disposal (f)	ton	107	300	32,100
Operational Monitoring	samples	100	150	15,000
Labor				
Operator (g)	hours	2,500	30	75,000
Supervisor (h)	hours	200	50	10,000
Variable Cost Subtotal				$434,724
Fixed Cost				
Maintenance				
Labor and Materials	7% of Capital Investment			118,210
Fixed Cost Subtotal				$118,210
Total Annual Operating Cost				$552,934

Notes:
(a) – The cost for the Five-Year Review has been divided evenly over five years
(b) – Operating cost for metal precipitation includes power and chemicals
(c) - Untreated ground water
(d) – Electrical includes power for pumps, UV lights, and misc. electrical for heating building, lighting, etc
(e) - Assumes 335 pounds of GAC/55 gallon drum
(f) – Includes disposal of any solids or from equilization tank and disposal of metal hydroxide sludge from metal precipitation
(g) – Two operators on-site 3.0 days/week
(h) – One supervisor 4 hours/week to review operation of process

Source: Arthur D. Little, Inc.

The alternative would also provide treatment of the contamination on site, except for small volumes of residuals such as the metal hydroxide sludge for the precipitation system and the spent carbon from the polishing system. The alternative would not pose a short-term risk to human health or the environment and would maximize the amount of water that was returned to the aquifer.

Compliance with ARARs

The alternative would not meet the preliminary remedial goals in 30 years but would achieve an incremental carcinogenic risk of 10^{-4} and a hazard index of 1. The alternative would meet all action-specific ARARs, including:

- No state and federal safe drinking water regulations exist for the contaminants of concern; therefore, the extracted ground water will be treated to ensure that each compound meets a hazard index equal to or less than 1, an excess cancer risk of greater than 10^{-6}, or the compound's detection limit prior to its return to the aquifer.

- State surface water discharge or underground injection regulations on the disposal of the treated ground water.

- All RCRA requirements will be met in regard to the transport and disposal of the residuals from the treatment process. The exposure concentration in the spent carbon will be equal to or less than 7%, which is well below the explosive limits of 10% (Arthur D. Little, 1987). A TCLP analysis of the spent GAC would have to be performed to ensure that the DNT concentration is below the RCRA limit.

Long-Term Effectiveness

The residual risk that would remain on site due to contamination in the ground water would be reduced to a hazard index of 2 and a carcinogenic risk of $3x10^{-4}$ in 30 years. Without active contamination treatment, the risk reduction would not be reached for an estimated 330 years.

Treatment residuals that are generated during the remediation of the ground water would be disposed of in a manner to eliminate unacceptable risks. The metal hydroxide sludges from the metal precipitation unit would be disposed of in a solid waste landfill depending on the results of a TCLP analysis, and the spent GAC would be shipped off site, where the contaminants would be destroyed by incineration or by another type of thermal treatment (e.g., regeneration or a cement kiln). Any free product removed from the equalization tank would be shipped off site for treatment and disposal.

The alternative would be operated until the ground water met a carcinogenic risk of $1x10^{-4}$ and a hazard index of 1, and the contaminants would be either destroyed in the UV/oxidation system or when the carbon is incinerated or by another type of thermal treatment (e.g., regeneration or a cement kiln). Therefore, no long-term controls would be necessary. All the technologies that would be used in this alternative are considered reliable.

This alternative would require five-year reviews to evaluate whether the alternative is protective of public health and the environment. The five-year reviews would be initiated five years after the start of the remedial action and would continue until no contaminants remain at the site above levels that allow for unrestricted use and unlimited exposure.

Reduction of Toxicity, Mobility, or Volume Through Treatment

The UV/oxidation system would irreversibly destroy the contaminants directly by oxidizing the contaminants. Any remaining contaminants would be removed by the GAC system. The UV/oxidation system would remove approximately 90% of the contamination from the ground water stream (ICF Kaiser Engineers, 1993). The remaining contaminants would be treated using the GAC system. The contamination adsorbed on the GAC will be irreversibly destroyed by incineration of the carbon at the off-site facility or by another type of thermal treatment (e.g., regeneration or a cement kiln). This treatment system will reduce the volume, toxicity, and mobility of the contaminants.

The metal precipitation system will generate metal hydroxide sludges at a rate of approximately 107 tons/year. These sludges will be disposed of off site as a solid waste depending on the results of a TCLP analysis. In addition to the sludges, an estimated 50 pounds of sediment will be collected each year in the equalization tank that will be analyzed and disposed of on site if found to be free of contamination.

Short-Term Effectiveness

The operation of the UV/oxidation system is not expected to increase the risk to the community or the environment because the contaminants will be irreversibly destroyed or adsorbed on the GAC and incinerated off site. The risks to the workers and the environment from using the acids, bases, and the ozone would be minimized through the use of engineering controls and personal protective equipment.

The alternative would meet a carcinogenic risk of 10^{-4} and a hazard index of within 30 years. If no active remediation alternative is implemented at the site, the ground water will not meet the remedial action objectives for an estimated 330 years.

Implementation

The construction and operation of the UV/oxidation system can be easily implemented and is technically capable of treating the contaminants in the ground water. The capacity of the UV/oxidation system can be increased if additional ground water needs to be treated or the concentration of contamination is greater than expected.

There is some uncertainty surrounding the reinfiltration of treated ground water into the lagoons to flush the remaining contaminants from the soils. Because there is the potential for the reinfiltration spreading the contamination, the ground water in the vicinity of the lagoons will have to be monitored to ensure that reinfiltration is not adversely affecting the ability to remediate the ground water. If there is a concern, then the ground water will be switched to the reinfiltration galleys upgradient.

No special equipment, materials, or technical specialists would be required for the implementation of the UV/oxidation system. Vendors are also currently available for the supply and incineration of the GAC.

State and local coordination would be required for the implementation of legal restrictions on the use of ground water at the site and the discharge of treated ground water to the environment.

Cost

The capital and operating costs are presented in Section 4.2.7.8 and Section 4.2.7.9, respectively.

4.2.8 Alternative 5B - UV/ Oxidation (10 Years, Remediated to a Carcinogenic Risk of $1x10^{-4}$ and a Hazard Index of 1)

In this alternative, the ground water will be extracted from a series of three wells over a 10-year period to remediate the ground water to 77 µg/L for RDX and 18 µg/L for TNT (risk-based cleanup level at $1x10^{-4}$ and a hazard index of 1, respectively). The ground water will be treated by hydroxide precipitation to remove the background metals from the contaminated ground water and then treated by UV/oxidation to destroy the explosives (see Figure 4.2.3-1). The results of a recent treatability study conducted at the Milan Army Ammunition Plant (ICF Kaiser Engineers, 1993), which has a ground water contaminant chemistry similar to that at Umatilla, indicate that it is not economically feasible to utilize UV/oxidation for complete contaminant destruction. Therefore, granular activated carbon (GAC) with off-site incineration of the spent carbon will be included as a polishing step to the primary UV/oxidation treatment.

After the ground water has been treated to meet all risk-based cleanup levels, it will initially be pumped to the explosive washout lagoons, where it will be allowed to reinfiltrate into the soils under the lagoons. Reinfiltration of the treated ground water into the lagoons will flush the remaining soil contamination into the ground water table, where it will be collected downgradient in the extraction wells. After approximately 6 months the reinfiltration of the treated ground water will be moved to infiltration galleys 400 to 800 feet upgradient of the lagoons.

In addition, this alternative will require ground water monitoring, five-year reviews, and institutional controls, which will continue until the contamination has been remediated to the detection limits stated above.

4.2.8.1 Institutional Controls. While the ground water is being remediated, institutional controls will be needed to restrict access to the contaminated aquifer, the contaminated ground water remediation equipment and the interconnecting piping. The level of institutional controls is similar to that previously discussed in Section 4.2.2, Alternative 2, and will not be repeated here.

4.2.8.2 Monitoring. The monitoring program would sample the existing monitoring wells and is identical to the program presented in Section 4.2.2.2, Monitoring for the Institutional Control Alternative.

4.2.8.3 Five-Year Reviews. In addition to the monitoring of the ground water and the institutional controls, this alternative would also require five-year reviews intended to evaluate whether the alternative remains protective of public health and the environment. The five-year reviews would be initiated five years after the start of the remedial action and continue until no contaminants remain at the site above levels that allow for unrestricted use and unlimited exposure. These reviews would be identical to the reviews described for the No Action alternative (see the introduction to Section 4.2, Individual Analysis of Alternatives).

4.2.8.4 Ground Water Extraction. The extraction method for this ground water alternative would be identical to the extraction method described for Alternative 3A (see Section 4.2.3.4, Ground Water Extraction), except that the total pumping rate would be 200 gallon per minute (gpm). Figure 4.2.8-1 presents the extraction well locations and the predicted ground water capture zone when the extraction wells are operating. Intermediate (15 years) and final (10 years) contour maps are presented in Figures 4.2.8-2 to 4.2.8-5. These figures, along with the capture zone, demonstrate that this alternative will remediate the site and capture the reinfiltrated ground water.

4.2.8.5 Equalization. The equalization method for this ground water alternative would be identical to the equalization method described for Alternative 3A (see Section 4.2.3.5, Equalization), except that extracted ground water would be pumped to a 10,000-gallon equalization tank that would provide an approximately 50-minute retention time.

4.2.8.6 Ultraviolet/ Oxidation

4.2.8.6.1 Metal Precipitation. The metal precipitation method for this ground water alternative would be identical to the metal precipitation method described for Alternative 3A (see Section 4.2.3.6.1, Metal Precipitation), except that operating parameters, and where appropriate the volume of material required on a daily basis, for the operation of such a metal precipitation system at the flow rate for this alternative would be:

Parameter	Operating Condition
$KMnO_4$ Dose	40 mg/L (43 kg/day)
Operating pH	11.0 units
NaOH Dose	400 mg/L (436 kg/day 50% NaOH)
Anionic Polymer Dose	3 mg/L (3.3 kg/day)
H_2SO_4 Dose	490 mg/L (530 kg/day 50% H_2SO_4)
Sludge Production	0.75 tons/day (@ 30% solids)

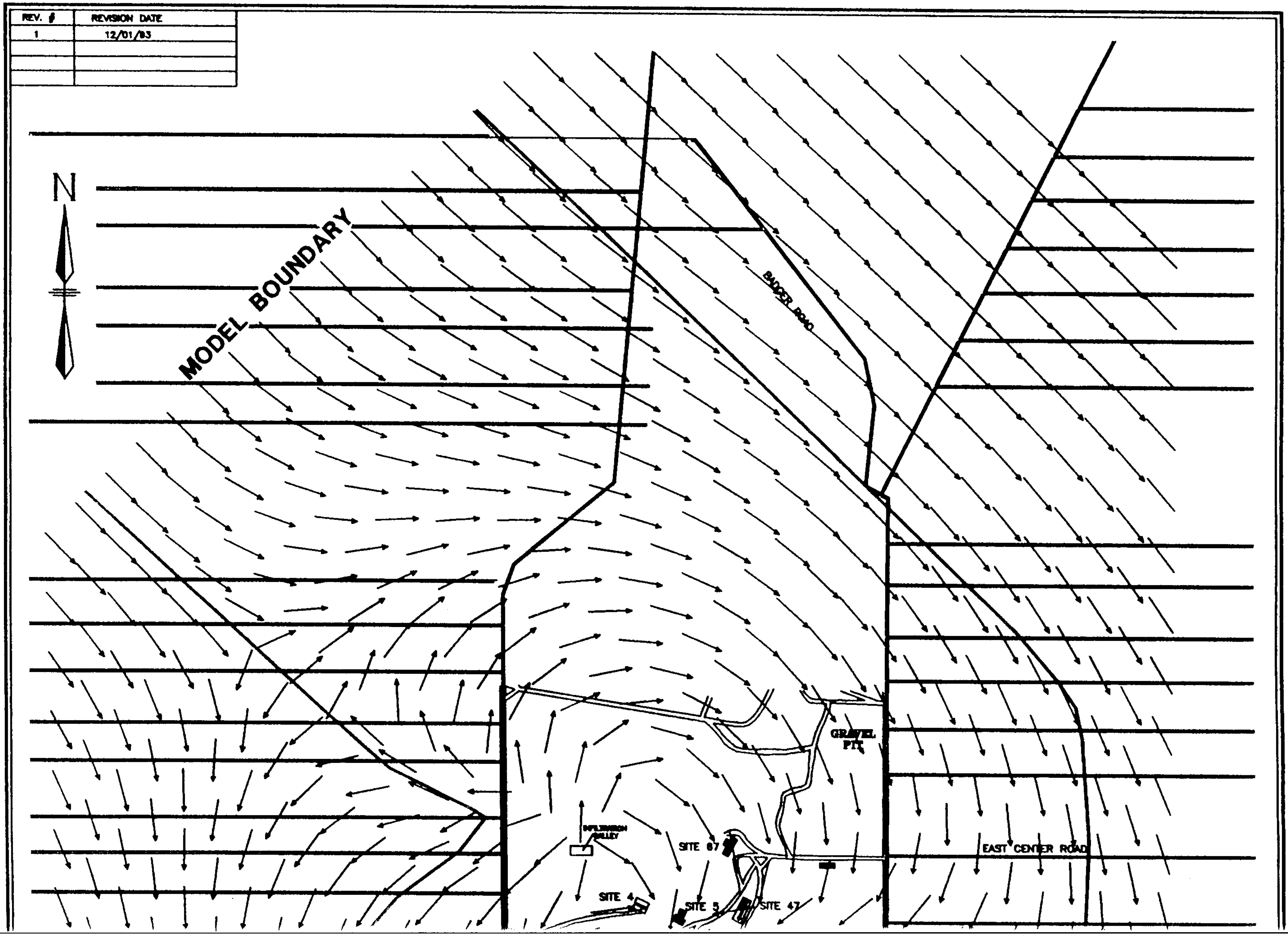
4.2.8.6.2 UV/Oxidation. The ultraviolet/oxidation method for this alternative would be identical to the method described in Section 4.2.3.6.2, UV/Oxidation, and will not be repeated here.

4.2.8.6.3 GAC Polishing. The carbon polishing system for this option would be identical to that described in Section 4.2.3.6.3, GAC Polishing, except that the carbon use rate was calculated to be 19 pounds carbon/day. Therefore, each carbon bed would last approximately 107 days before being removed for incineration or another type of thermal treatment.

4.2.8.7 Reinfiltration. The reinfiltration method for this alternative would consist of a slightly larger reinfiltration galley, approximately 3,208 square feet, but would otherwise be identical to the method described for Alternative 3A (see Section 4.2.3.7, Reinfiltration). A description of this process will not be repeated here.

4.2.8.8 Capital Cost. The capital cost for the UV/oxidation system is approximately $2.9 million, as presented in Table 4.2.8-1. The capital cost of this alternative is strongly dependent on the cost of the UV/oxidation system, which is approximately 50% of the overall capital cost. The cost of the UV/oxidation system would be increased if the volume of water to be treated increased or the retention time to reach the preliminary remedial goals increased. If the water volume to the UV system was increased or the retention time was increased by 50% the capital cost would be increased from $2.9 million to $3.7 million. The capital cost would also be increased if the number of extraction wells needed to be increased to ensure that the capture zone was maintained; if the number of wells was doubled the total capital cost would only be increased by approximately $175,000.

4.2.8.9 Operating Cost. The annual operating cost for the UV/oxidation system is approximately $1.1 million, as presented in Table 4.2.8-2. Using the annual operating cost, the NPV was calculated for the 10-year scenario using a 5% and a 10% interest rate.r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MODEL BOUNDARY
BADGER ROAD
GRAVEL PIT
EAST CENTER ROAD
INFILTRATION GALLEY
SITE 67
SITE 4
SITE 5
SITE 47

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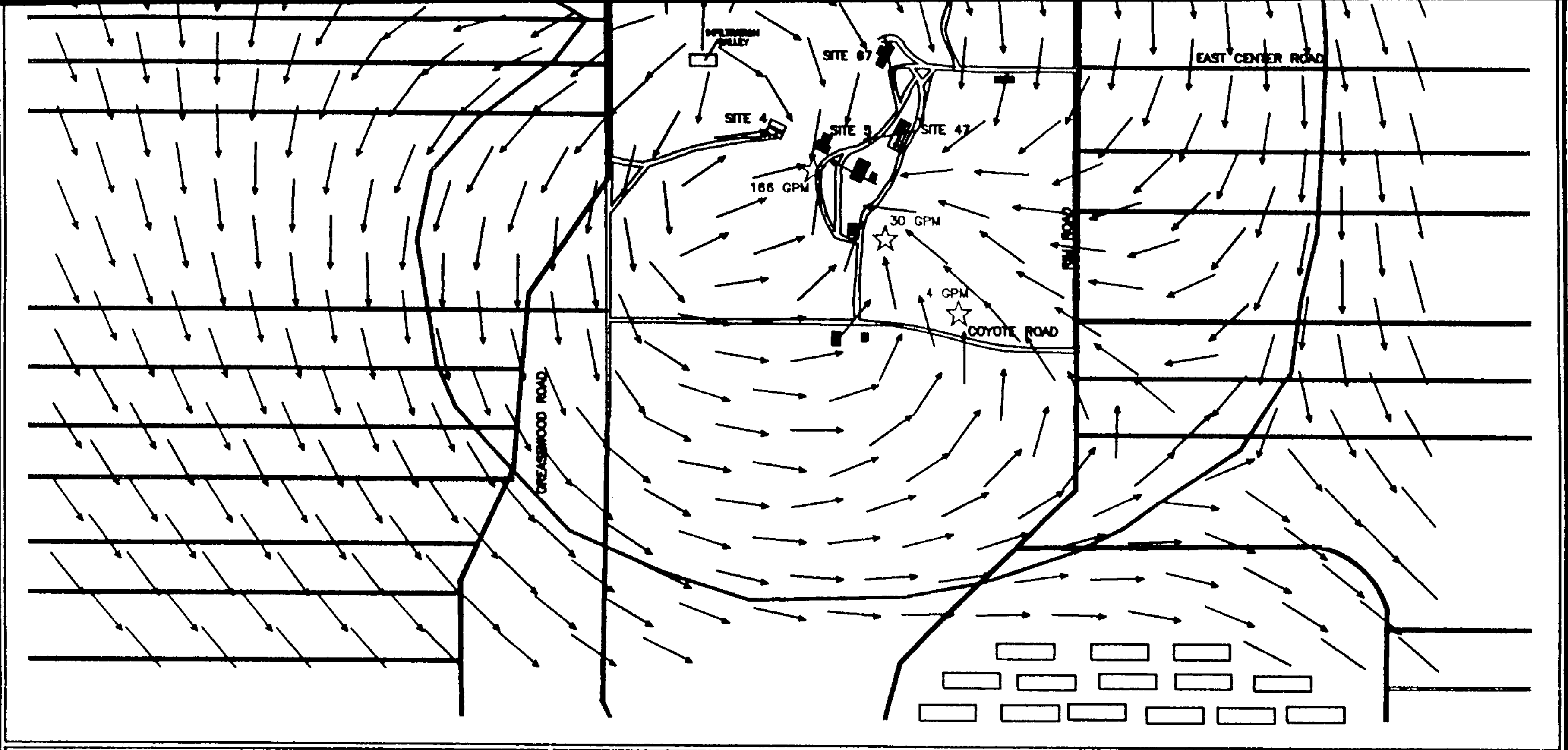
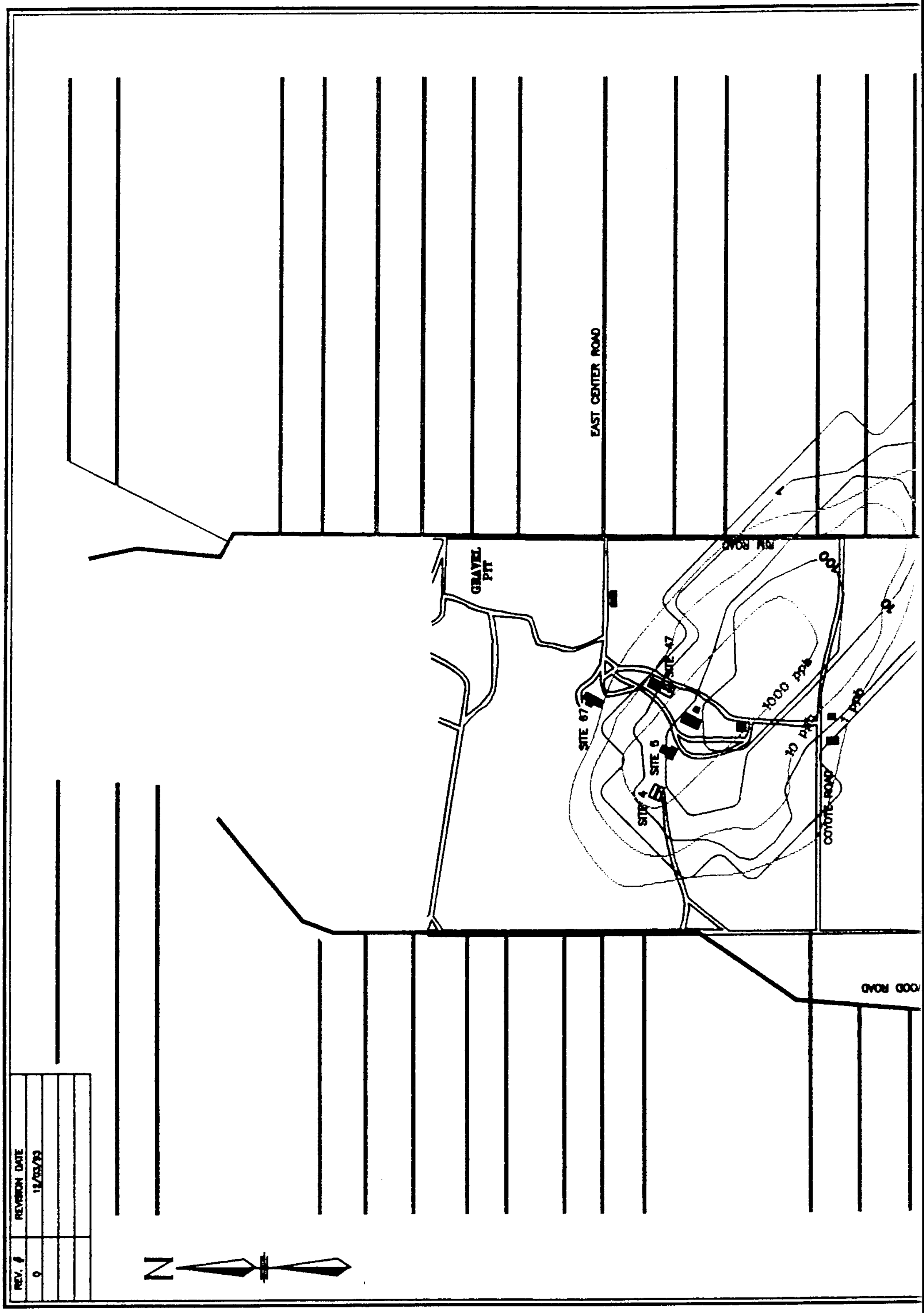

SITE 67
SITE 4
SITE 5
SITE 47
EAST CENTER ROAD
166 GPM
30 GPM
4 GPM
COYOTE ROAD
GREASEWOOD ROAD

PREPARED FOR: USAEC		☆ 30 GPM	Extraction Well Location Extraction Flow Rate	TITLE:
DATE: DEC. '93	DWG. NO.: 67062-046	⟶	Ground Water Gradient Direction	Approximate Contaminant Capture Zone For the 10-Year Extraction System 10 $^{-4}$ Risk Level
SCALE: 0 — 3000 FT.		▬	Approximate Contaminant Capture Zone	
		Arthur D Little		

Figure 4.2.8-1: Approximate Contaminant Capture Zone for the 10-Year Extraction System 10^{-4} Risk Level

270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RIM ROAD
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1000 ppb
100
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COYOTE ROAD
OOD ROAD
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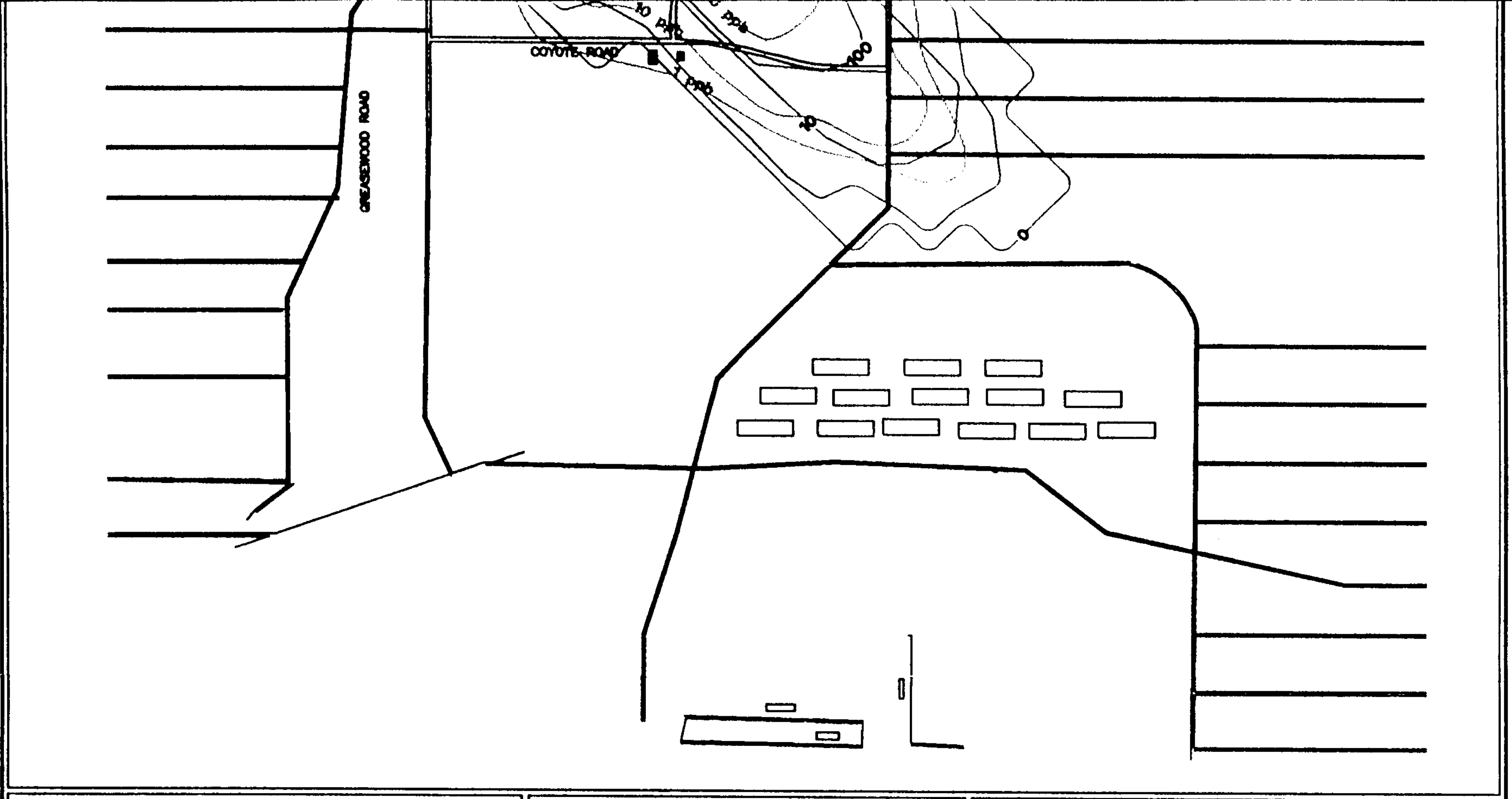
REV. #	REVISION DATE
0	12/03/93

1 of 2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GREASEWOOD ROAD
10 ppb
1 ppb
100
10
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ppb

PREPARED FOR:
USAEC

DATE:
DEC. '93

DWG. NO.:
67062-052

SCALE:
0 3000 FT.

—— Simulated RDX Concentrations after 5 years (ppb)

—— Simulated Current RDX Concentrations (ppb)

Source: Arthur D. Little, Inc.

Arthur D Little

TITLE:

Simulated RDX Concentrations after 5 years with a Remediation Objective of an Incremental Risk of 1 x 10^{-4} and a Hazard Index of 1

Figure 4.2.8-2: Simulated RDX Concentrations After 5 Years

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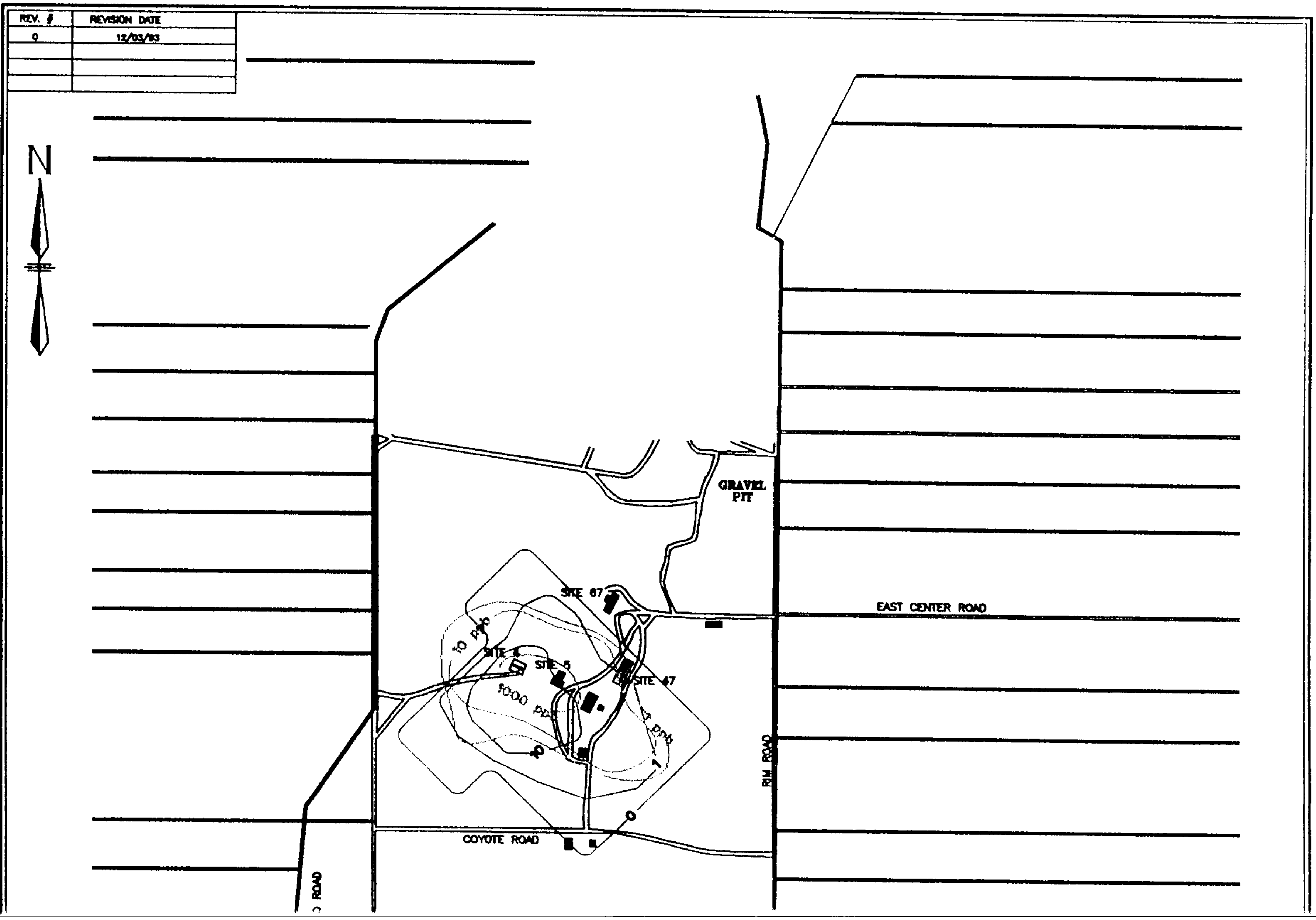
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GRAVEL PIT
EAST CENTER ROAD
RIM ROAD
COYOTE ROAD
ROAD
SITE 67
SITE 4
SITE 5
SITE 47
10 ppb
5000 ppb
1 ppb
10
1
0

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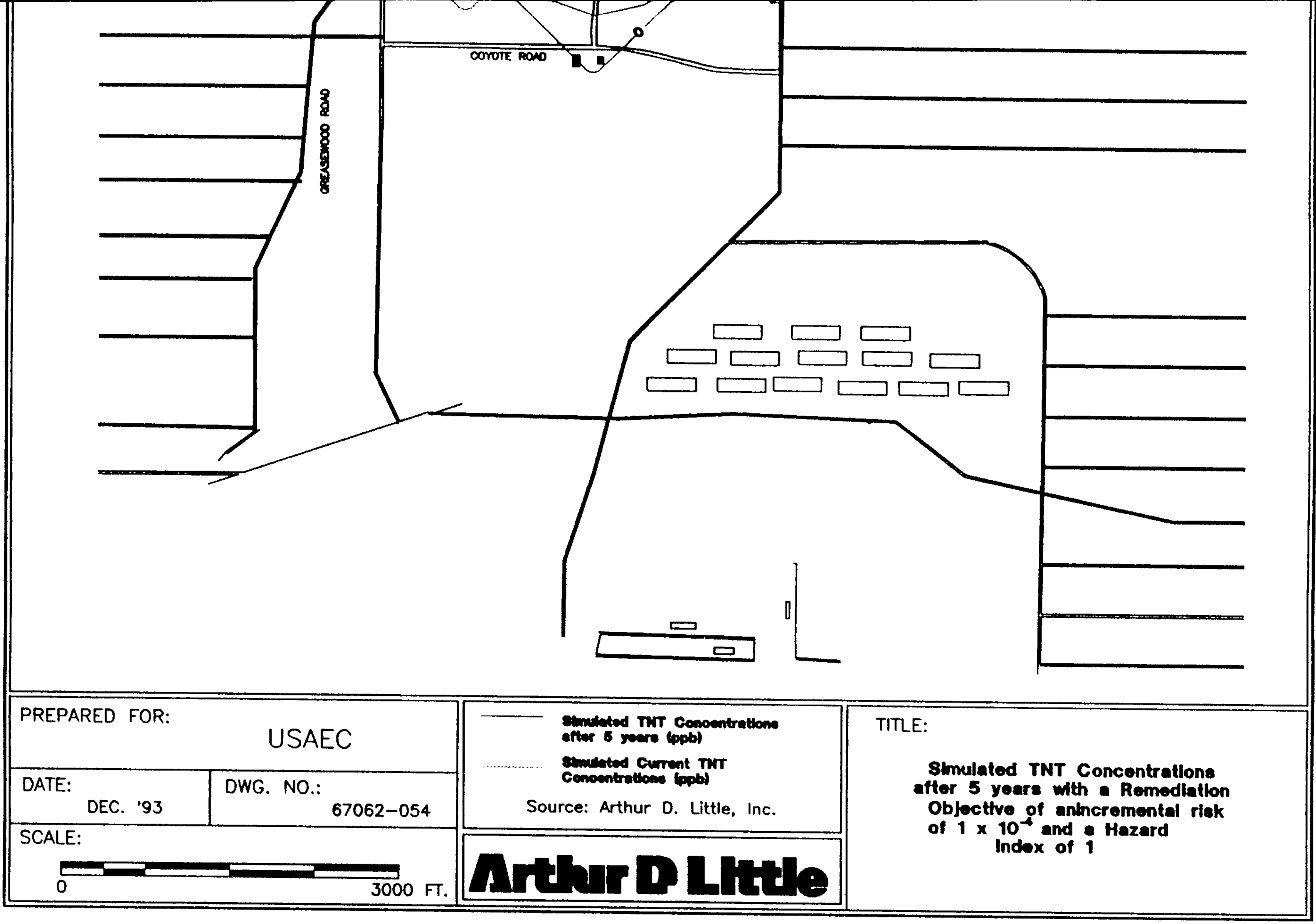
1 of 2



PREPARED FOR:
USAEC

DATE:
DEC. '93

DWG. NO.:
67062–054

SCALE:
0 3000 FT.

Simulated TNT Concentrations after 5 years (ppb)

Simulated Current TNT Concentrations (ppb)

Source: Arthur D. Little, Inc.

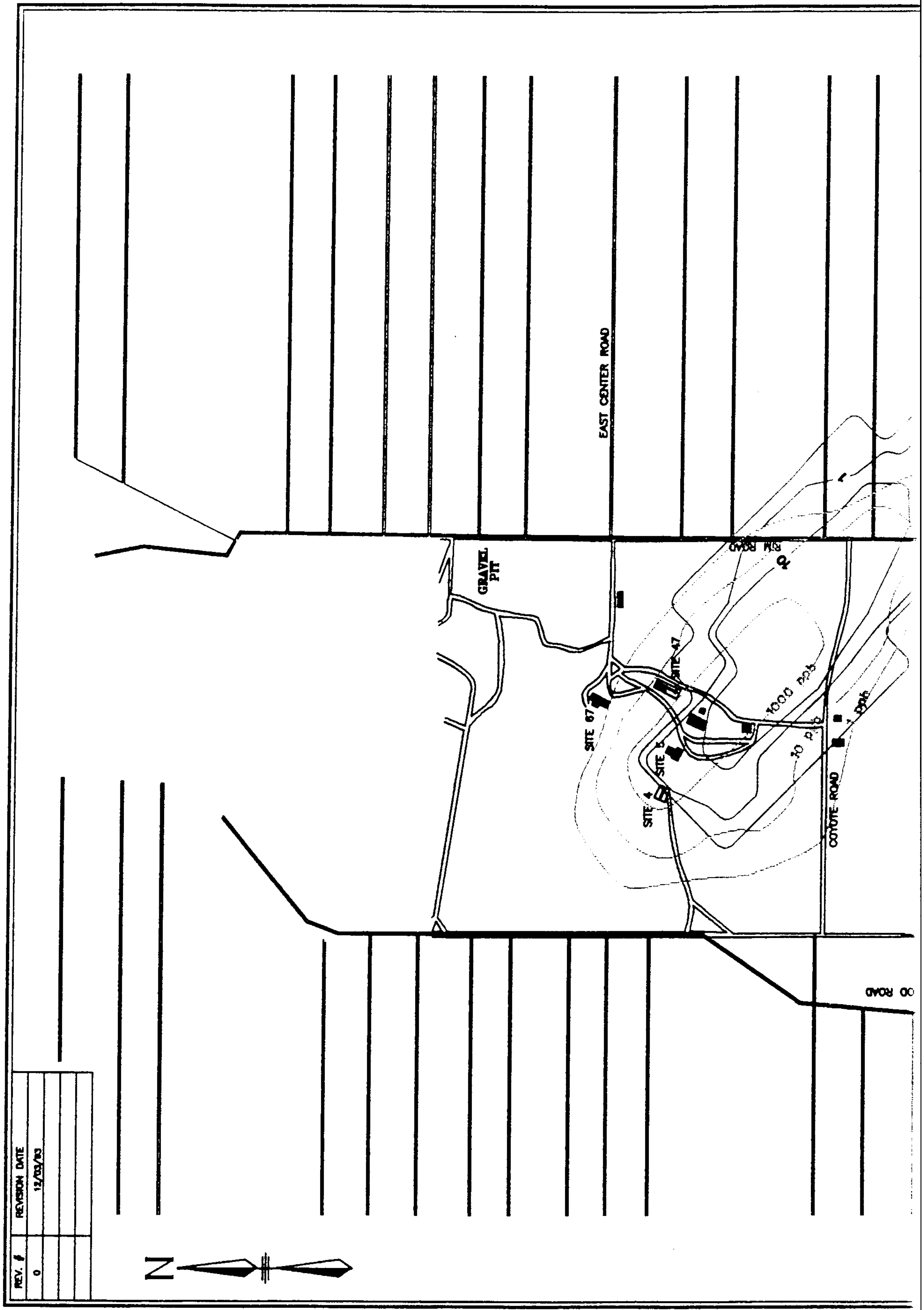
Arthur D Little

TITLE:

Simulated TNT Concentrations after 5 years with a Remediation Objective of anincremental risk of 1 x 10^{-4} and a Hazard Index of 1

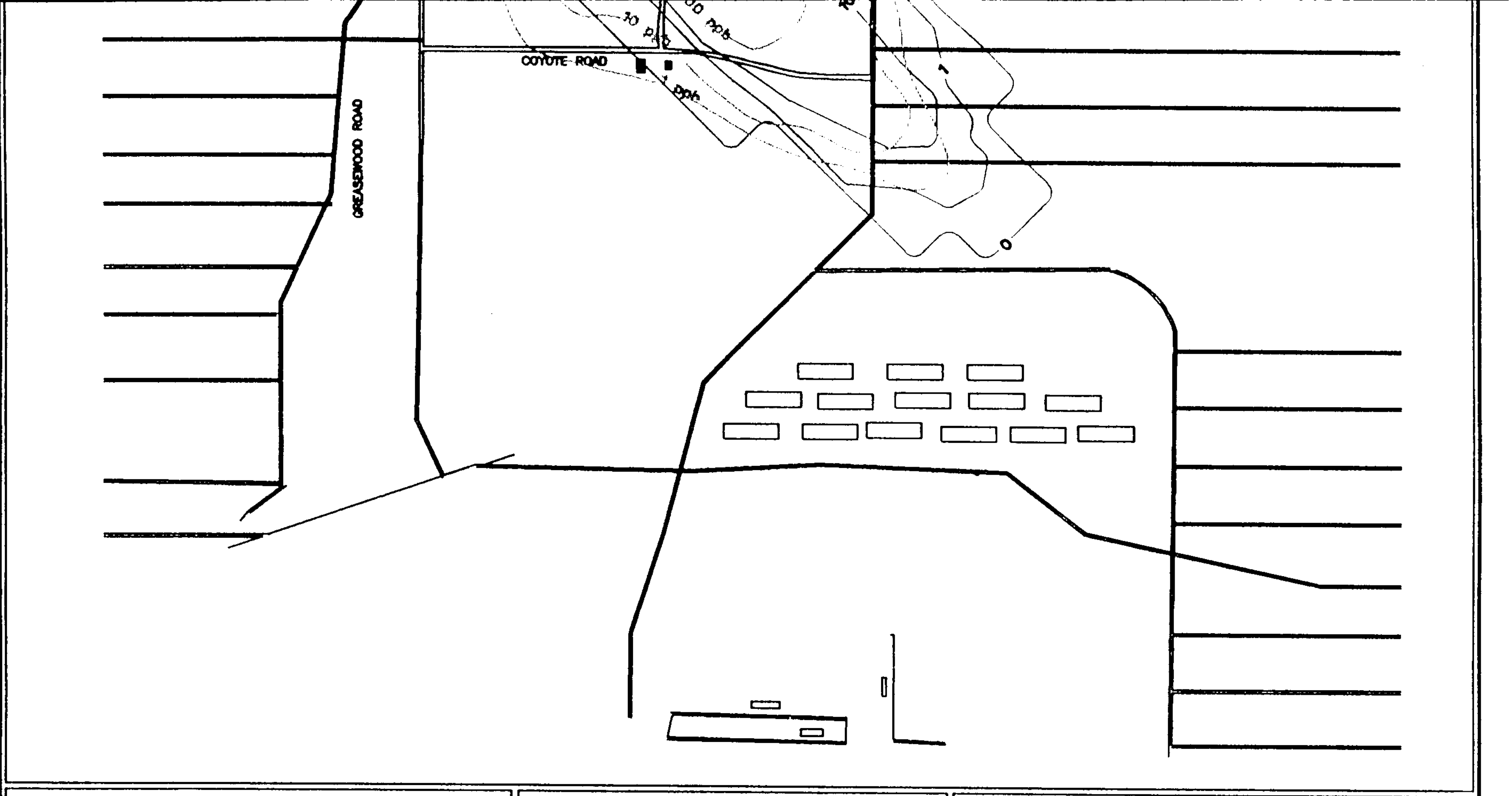
Figure 4.2.8-3: Simulated TNT Concentrations After 5 Years

2572


EAST CENTER ROAD
GRAVEL PIT
RIM ROAD
SITE 47
SITE 67
SITE 5
SITE 4
1000 ppb
10 ppb
1 ppb
COYOTE ROAD
OO ROAD
N

REV. #	REVISION DATE
0	12/03/03

1 of 2



PREPARED FOR:
USAEC

DATE:
DEC. '93

DWG. NO.:
67062-051

SCALE:
0 3000 FT.

—— **Simulated RDX Concentrations after 10 years (ppb)**

········ **Simulated Current RDX Concentrations (ppb)**

Source: Arthur D. Little, Inc.

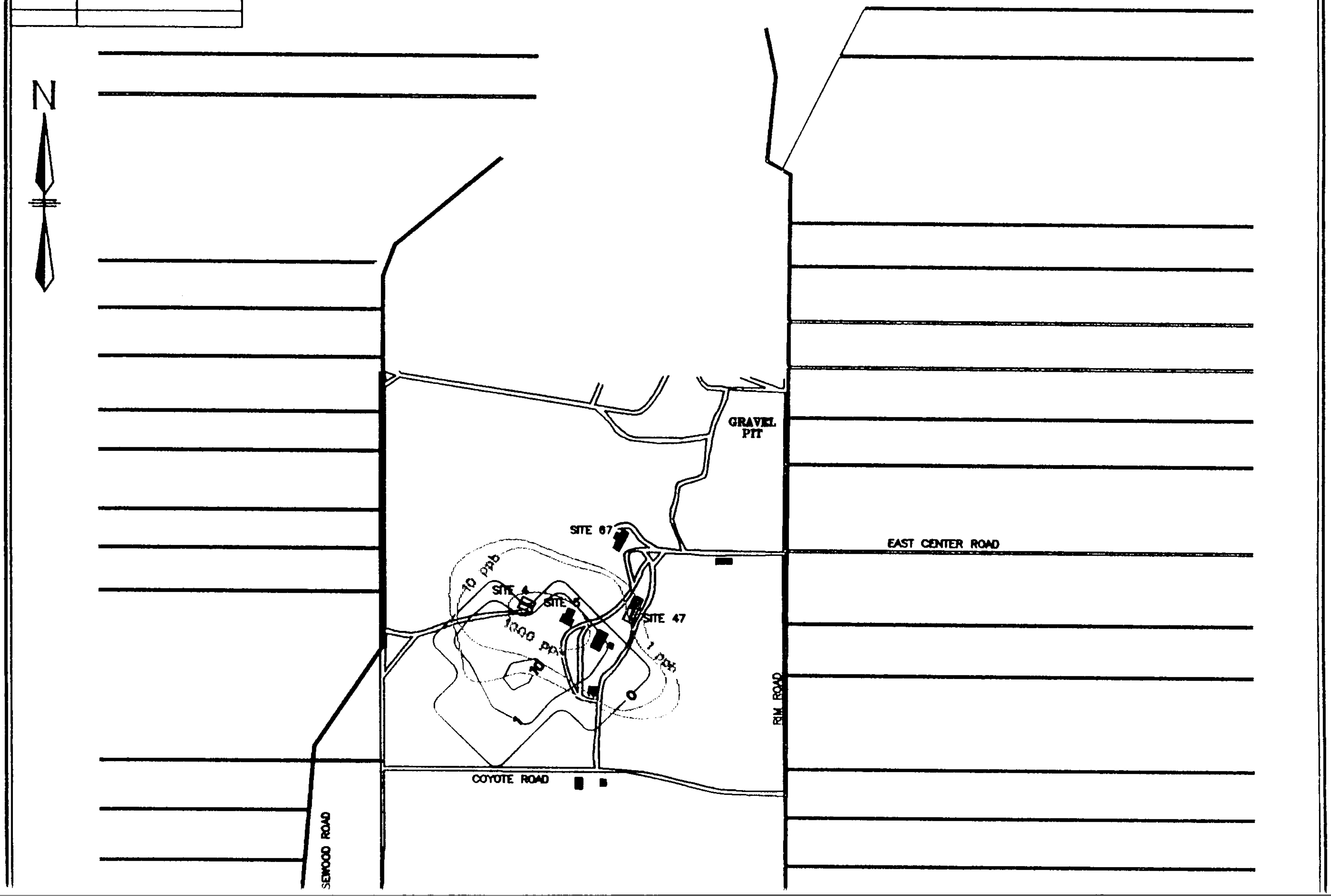
Arthur D Little

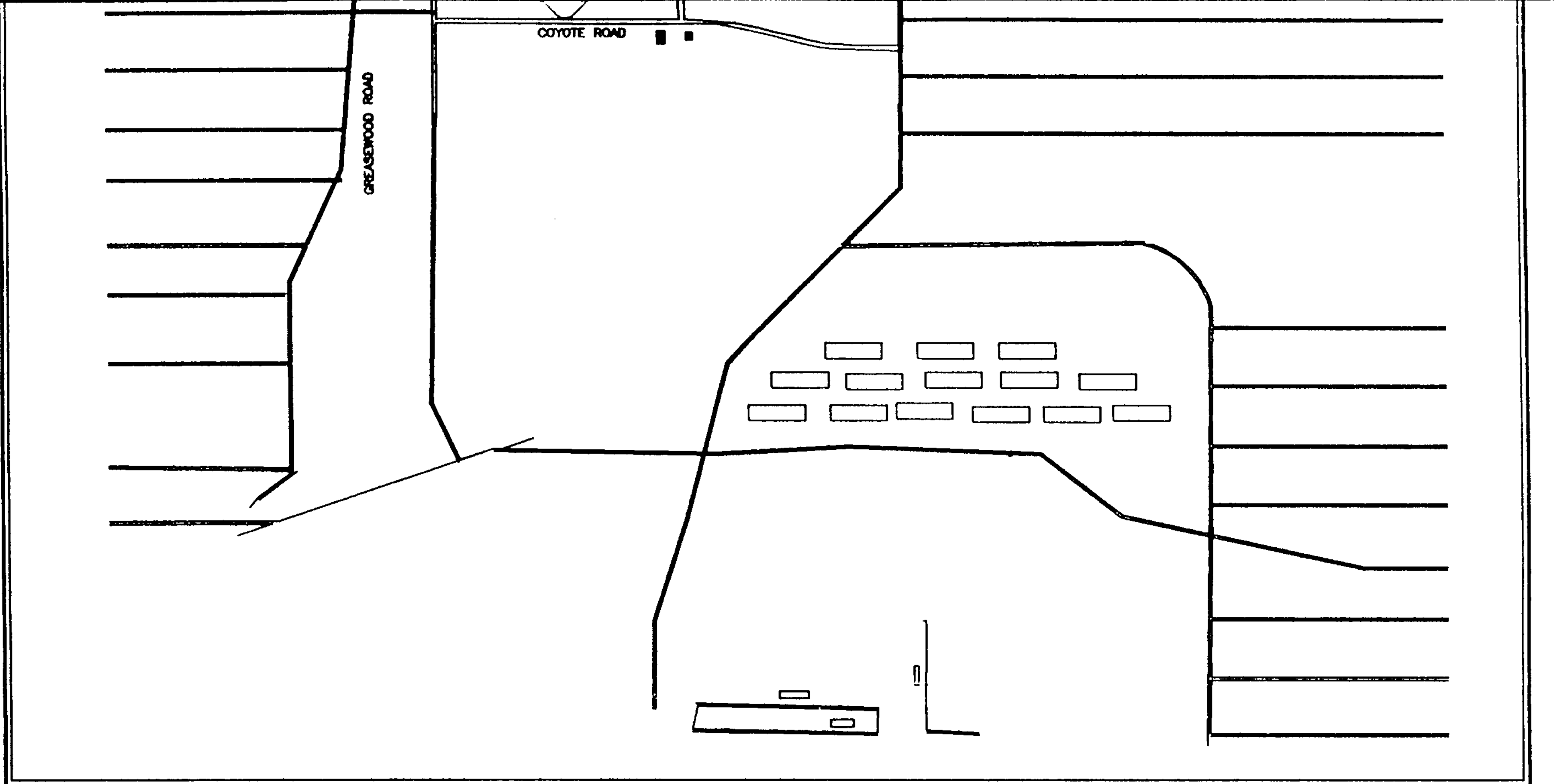
TITLE:

Simulated RDX Concentrations after 10 years with a Remediation Objective of an Incremental Risk of 1 x 10^{-4} and a Hazard Index of 1

Figure 4.2.8-4: Simulated RDX Concentrations After 10 Years

REV. #	REVISION DATE
0	12/03/93


N
GRAVEL PIT
EAST CENTER ROAD
SITE 67
SITE 47
SITE 4
SITE 5
10 ppb
1000 pp
1 ppb
RIM ROAD
COYOTE ROAD
SEWOOD ROAD



PREPARED FOR:
USAEC

DATE:
DEC. '93

DWG. NO.:
67062–053

SCALE:
0 3000 FT.

——— Simulated TNT Concentrations after 10 years (ppb)

- - - - Simulated Current TNT Concentrations (ppb)

Source: Arthur D. Little, Inc.

Arthur D Little

TITLE:

Simulated TNT Concentrations after 10 years with a Remediation Objective of an Incremental Risk of 1 x 10^{-4} and a Hazard Index of 1

Figure 4.2.8-5: Simulated TNT Concentrations After 10 Years

Table 4.2.8-1: Capital Cost for Ultraviolet/Oxidation – Alternative 5B

Item No.	Item	Units	Unit Cost (1993 $)	# of Units	Total Cost (1993 $)
100	**Extraction**				
101	GW Wells - 8 inch, 155 feet	Well	30,000	3	90,000
102	GW Well Pumps - 200 gpm, 5 hp	Pump	2,200	3	6,600
103	GW Buried Pipeline	Pipeline/500 ft	4,250	6	25,500
200	**Equalization**				
201	Equalization/Settling - 10,000 gal	Tank	25,400	1	25,400
202	Feed Pump - 250 gpm, 5 hp	Pump	2,300	2	4,600
300	**Metal Precipitation**	System	230,000	1	230,000
301	pH Control System				
302	Oxidant Addition Pump				
303	Treatment Tank with Mixer				
304	Polymer Feed System				
305	Clarification System				
306	Sludge Thickening System				
307	Filter Press				
308	Multi-Media Filter				
400	**UV/Oxidation**	System	1,200,000	1	1,200,000
401	UV Reactor				
402	UV Feed Pump				
403	Ozone Generation and Destruction				
500	**Granular Activated Carbon**				
501	GAC Tank - 2000 gal	Tank	4,250	2	8,500
503	GAC - 2000 lb	Bed	4,500	2	9,000
504	Discharge Pump - 250 gpm, 7 hp	Pump	2,500	2	5,000
600	**Reinfiltration Galley**				
601	Excavation	C.Y.	2	1,326	2,984
602	Crushed Stone	C.Y.	19	441	8,423
603	Backfill	C.Y.	2	132	222
604	Infiltration Galley	Galley	200	203	40,600
700	**Lagoon Lining**				
701	HDPE Lining	Lagoon	3,000	2	6,000
702	Crushed Stone	C.Y.	19	520	9,932
Equipment Subtotal					**$1,672,760**
Remedial Design / Planning		10 % of Purchased Equipment Cost			167,276
Plumbing		10 % of Purchased Equipment Cost			167,276
Electrical		10 % of Purchased Equipment Cost			167,276
Instrumentation and Controls		10 % of Purchased Equipment Cost			167,276
Construction and Installation		30 % of Purchased Equipment Cost			501,828
Treatment System Building		sq feet	27	1,200	32,400
Installation Subtotal					**$1,203,332**
Total Capital Cost					**$2,876,093**

Source: Arthur D. Little, Inc.

Table 4.2.8-2: Annual Operating Cost for Ultraviolet/Oxidation - Alternative 5B

Item	Units	Units/ Year	Unit Cost (1993 Dollars)	Annual Cost (1993 Dollars)
Variable Cost				
Monitoring				
Sample Collection	hours	640	30	19,200
Supervision	hours	32	50	1,600
Sample Analysis	samples	152	150	22,800
Data Review and Reporting	hours	32	65	2,080
Five -Year Review (a)	hours	50	80	4,000
Metals Precipitation (b)	1000 gal (c)	105,120	0.4	42,048
Electrical (d)	kw/yr	9,100,000	0.06	546,000
Ozone	1000 gal (c)	105,120	0.25	26,280
Granular Activated Carbon				
GAC Bed - 2000 lb	ton	3.4	4500	15,300
GAC Incineration (e)				
Polyethylene Lined Drums	drum	20.3	25	508
Shipping	drum	20.3	125	2,538
Treatment/Disposal	drum	20.3	420	8,526
Disposal (f)	ton	273	300	81,900
Operational Monitoring	samples	100	150	15,000
Labor				
Operator (g)	hours	2,500	30	75,000
Supervisor (h)	hours	200	50	10,000
Variable Cost Subtotal				$872,779
Fixed Cost				
Maintenance				
Labor and Materials	7% of Capital Investment			201,330
Fixed Cost Subtotal				$201,330
Total Annual Operating Cost				$1,074,109

Notes:
(a) – The cost for the Five-Year Review has been divided evenly over five years
(b) – Operating cost for metal precipitation includes power and chemicals
(c) - Untreated ground water
(d) – Electrical includes power for pumps, UV lights, and misc. electrical for heating building, lighting, etc
(e) - Assumes 335 pounds of dewatered GAC/55 gallon drum
(f) – Includes disposal of any solids or from equilization tank and disposal of metal hydroxide sludge from metal precipitation
(g) – Two operators on-site 3.0 days/week
(h) – One supervisor 4 hours/week to review operation of process

Source: Arthur D. Little, Inc.

Time Frame	Annual Cost	5% Interest Rate		10% Interest Rate	
		Discount Factor	NPV	Discount Factor	NPV
1-10 years	\$1.1M	7.9	\$8.7M	6.0	\$6.6M

The operating cost for this alternative is strongly dependent on the electrical cost for the operation of the UV/oxidation system. The electrical cost would increase if the size of the UV/oxidation system was increased. A 50% increase in the size of the UV/oxidation system would increase the electrical costs from \$550,000 to \$910,000, and the 5% NPV would increase from \$8.7 million to \$11.6 million.

4.2.8.10 NCP Evaluation Criteria. The degree to which UV/oxidation of the contaminated ground water meets the NCP evaluation criteria is discussed below.

Overall Protection of Human Health and the Environment

This alternative would return the ground water to its potential beneficial use within 10 years. Upon achieving the remedial action objectives, the total hazard index for the ingestion of ground water for all compounds, at reasonable maximum exposure, would be reduced from 60 to 2. The total incremental cancer risk for the ingestion of ground water for all compounds at reasonable maximum exposure would be reduced from $2x10^{-3}$ to 3×10^{-4} (see Section 2.1, Remedial Action Objectives).

The alternative would also provide treatment for the contamination on site, except for small volumes of residuals such as the metal hydroxide sludge for the precipitation system and the spent carbon from the polishing system. The alternative would not pose a short-term risk to human health or the environment and would maximize the amount of water that was returned to the aquifer.

Compliance with ARARs

The alternative would not meet the preliminary remedial goals in ten years but would achieve an incremental carcinogenic risk of 10^{-4} and a hazard index of 1. The alternative would meet all action-specific ARARs, including:

- No state and federal safe drinking water regulations exist for the contaminants of concern; therefore, the extracted ground water will be treated to ensure that each compound meets a hazard index equal to or less than 1, an excess cancer risk of greater than 10^{-6}, or the analytical detection limit prior to its return to the aquifer.
- State surface water discharge or underground injection regulations on the disposal of the treated ground water.

- All RCRA requirements will be met in regard to the transport and disposal of the residuals from the treatment process. The explosive concentration in the spent carbon will be equal to or less than 7% which is well below the explosive limit of 10% (Arthur D. Little, 1987). A TCLP analysis of the spent GAC would have to be performed to ensure that the DNT concentration is below the RCRA limit.

Long-Term Effectiveness

The residual risk that would remain on site due to contamination in the ground water would be reduced to a hazard index of 2 and a carcinogenic risk of 3×10^{-4} in 10 years. Without active contamination treatment, the risk reduction would not be reached for an estimated 330 years.

Treatment residuals that are generated during the remediation of the ground water would be disposed of in a manner to eliminate unacceptable risks. The metal hydroxide sludges from the metal precipitation unit would be disposed of in a solid waste landfill depending on the results of a TCLP analysis, and the contaminants adsorbed on the spent GAC would be destroyed by off-site incineration or by another type of thermal treatment (e.g., regeneration or a cement kiln). Any solids removed from the equalization tank would be shipped off site for treatment and disposal.

The alternative would be operated until the ground water met a carcinogenic risk of 1×10^{-4} and a hazard index of 1, and the contaminants would be either destroyed in the UV/oxidation system or when the carbon is incinerated at the off-site facility or by another type of thermal treatment (e.g., regeneration or a cement kiln). Therefore, no long-term controls would be necessary. All the technologies that would be used in this alternative are considered reliable.

This alternative would require five-year reviews to evaluate whether the alternative is protective of public health and the environment. The five-year reviews would be initiated five years after the start of the remedial action and would continue until no contaminants remain at the site above levels that allow for unrestricted use and unlimited exposure.

Reduction of Toxicity, Mobility, or Volume Through Treatment

The UV/oxidation system would irreversibly destroy the contaminants directly by oxidizing the contaminants. Any remaining contaminants would be removed by the GAC system. The UV/oxidation system would remove approximately 90% of the contamination from the ground water stream (ICF Kaiser Engineers, 1993). The remaining contaminants would be treated using the GAC system. The contamination adsorbed on the GAC will be irreversibly destroyed by off-site incineration of the carbon or by another type of thermal treatment (e.g., regeneration or a cement kiln). This treatment system will reduce the volume, toxicity, and mobility of the contaminants.

The metal precipitation system will generate metal hydroxide sludges at a rate of approximately 273 tons/year. These sludges will be disposed of off site as a hazardous waste. In addition to the sludges, an estimated 150 pounds of sediment will be collected each year in the equalization tank that will be analyzed and disposed of on site if found to be free of contamination.

Short-Term Effectiveness

The operation of the UV/oxidation system is not expected to increase the risk to the community because the contaminants will be irreversibly destroyed or adsorbed on the GAC and incinerated off site. The risks to the workers from using the acids, bases, and the ozone would be minimized through the use of engineering controls and personal protective equipment.

The alternative would meet a carcinogenic risk of 10^{-4} and a hazard index of 1 within 10 years. If no active remediation alternative is implemented at the site, the ground water will not meet the remedial action objectives for an estimated 330 years.

Implementation

The construction and operation of the UV/oxidation system can be easily implemented and is technically capable of treating the contaminants in the ground water. The capacity of the UV/oxidation system can be increased if additional ground water needs to be treated or the concentration of contamination is greater than expected.

There is some uncertainty surrounding the reinfiltration of treated ground water into the lagoons to flush the remaining contaminants from the soils. Because there is the potential for the reinfiltration spreading the contamination, the ground water in the vicinity of the lagoons will have to be monitored to ensure that reinfiltration is not adversely affecting the ability to remediate the ground water. If there is a concern, then the ground water will be switched to the reinfiltration galleys upgradient.

No special equipment, materials, or technical specialists would be required for the implementation of the UV/oxidation system. Vendors are also currently available for the supply and incineration of the GAC.

State and local coordination would be required for the implementation of legal restrictions on the use of ground water at the site and the discharge of treated ground water to the environment.

Cost

The capital and operating costs are presented in Section 4.2.8.8 and Section 4.2.8.9, respectively.

4.2.9 Alternative 6A - Carbon Adsorption (30 Years, Remediated to a Carcinogenic Risk of $1x10^{-4}$ and a Hazard Index of 1)

In this alternative, the ground water will be extracted from a series of three wells over a 30-year period to remediate the ground water to 77 µg/L for RDX and 18 µg/L for TNT (risk-based cleanup level at $1x10^{-4}$ and a hazard index of 1, respectively). The extracted water will be treated with activated carbon to remove the explosives from the water stream (see Section 4.2.5.6, GAC Primary Treatment).

After the ground water has been treated to meet all risk-based cleanup levels, it will initially be pumped to the explosive washout lagoons, where it will be allowed to reinfiltrate into the soils under the lagoons. Reinfiltration of the treated ground water into the lagoons will flush the remaining soil contamination into the ground water table, where it will be collected downgradient in the extraction wells. After approximately 15 months the reinfiltration of the treated ground water will be moved to infiltration galleys 400 to 800 feet upgradient of the lagoons.

The GAC option would be designed to handle the same ground water flow rates and contaminant concentrations as the UV/oxidation system described in Section 4.2.3, Alternative 3A, and depicted in Figure 4.2.3-1. The spent carbon from the GAC treatment beds would be incinerated off site at any of the commercial hazardous waste incinerators described in Section 4.2.5.6 or treated using another type of thermal treatment; each of the incinerators listed in this section is capable of treating the spent carbon from this treatment system. Regeneration of the spent carbon contaminated with explosives is not feasible due to the destruction of carbon particles during regeneration; however, if regeneration becomes technically feasible, then regeneration of the carbon will be considered during the remedial action. In addition, this alternative will require ground water monitoring, five-year reviews, and institutional controls, which will continue until the contamination has been remediated to the detection limits stated above.

4.2.9.1 Institutional Controls. While the ground water is being remediated, institutional controls will be needed to restrict access to the contaminated aquifer, the contaminated ground water remediation equipment and the interconnecting piping. The level of institutional controls is similar to that previously discussed in Section 4.2.2, Alternative 2, and will not be repeated here.

4.2.9.2 Monitoring. The monitoring program would sample the existing monitoring wells and is identical to the program presented in Section 4.2.2.2, Monitoring, for the Institution Control Alternative.

4.2.9.3 Five-Year Reviews. In addition to the monitoring of the ground water and the institutional controls, this alternative would also require five-year reviews intended to evaluate whether the alternative remains protective of public health and the environment. The five-year reviews would be initiated five years after the start of the remedial action and continue until no contaminants remain at the site above levels that allow for unrestricted use and unlimited exposure. These reviews would be identical to the reviews described for the No Action alternative (see the introduction to Section 4.2, Individual Analysis of Alternatives).

4.2.9.4 Ground Water Extraction. The extraction method for this ground water alternative would be identical to the extraction method described for Alternative 3 (see Section 4.2.3.4, Ground Water Extraction), except that the total pumping rate would be 77 gallons per minute (gpm). Figure 4.2.7-1 presents the extraction well locations and the predicted ground water capture zone when the extraction wells are operating. Intermediate (15 years) and final (30 years) contour maps are presented in Figures 4.2.7-2 and 4.2.7-5. These figures, along with the capture zone, demonstrate that this alternative will remediate the site and capture the reinfiltrated ground water.

4.2.9.5 Equalization. The equalization method for this ground water alternative would be identical to the equalization method described for Alternative 3A (see Section 4.2.3.5, Equalization), except that extracted ground water would be pumped to a 3,500-gallon equalization tank that would provide an approximately 50 minute retention time.

4.2.9.6 GAC Primary Treatment. The GAC treatment method for this ground water alternative would be identical to the GAC treatment method described for Alternative 4A (see Section 4.2.5.6, GAC Primary Treatment), except that the volume of GAC required on a daily basis for the flow rate for this alternative would be approximately 72 pounds GAC per day (see Appendix C). Therefore, each bed would last approximately 28 days before being removed for incineration.

The off-site incineration method for this alternative would be identical to the method described for Alternative 4A (see Section 4.2.5.6, GAC Primary Treatment) and will not be repeated here.

4.2.9.7 Reinfiltration. The reinfiltration method for this alternative would consist of a reinfiltration galley identical to that described for Alternative 5A (see Section 4.2.7.8, Reinfiltration). A description of the reinfiltration process will not be repeated here.

4.2.9.8 Capital Cost. The capital cost for the GAC primary treatment system is approximately $0.35 million, as presented in Table 4.2.9-1. The capital cost for the GAC system is spread out fairly evenly between all the unit operations. A moderate increase in the flow rate or the concentration of contaminants in the inlet would not require a larger GAC system. The capital cost would also be increased if the number of extraction wells needed to be increased to ensure that the capture zone was maintained; if the number of wells was doubled the total capital cost would only be increased by approximately $175,000.

Table 4.2.9-1: Capital Cost for Granular Activated Carbon – Alternative 6A

Item No.	Item	Units	Unit Cost (1993 $)	# of Units	Total Cost (1993 $)
100	**Extraction**				
101	GW Wells - 8 inch, 155 feet	Well	30,000	3	90,000
102	GW Well Pumps - 70 gpm, 2.5 hp	Pump	1,375	3	4,125
103	GW Buried Pipeline	Pipeline/500 ft	4,250	6	25,500
200	**Equalization**				
201	Equalization/Settling - 3,500 gal	Tank	8,160	1	8,160
302	Feed Pump - 100 gpm, 2 hp	Pump	1,500	2	3,000
300	**Granular Activated Carbon**				
301	GAC Tank - 2000 gal	Tank	4,250	2	8,500
302	GAC - 2000 lb	Bed	4,500	2	9,000
303	Discharge Pump - 100 gpm, 3 hp	Pump	1,600	2	3,200
400	**Reinfiltration Galley**				
401	Excavation	C.Y.	2	442	995
402	Crushed Stone	C.Y.	19	147	2,808
403	Backfill	C.Y.	2	44	74
404	Infiltration Galley	Galley	200	69	13,800
500	**Lagoon Lining**				
501	HDPE Liner	Lagoon	3,000	2	6,000
502	Crushed Stone	C.Y.	19	520	9,932
Equipment Subtotal					**$185,093**
Remedial Design / Planning		10 % of Purchased Equipment Cost			18,509
Plumbing		10 % of Purchased Equipment Cost			18,509
Electrical		10 % of Purchased Equipment Cost			18,509
Instrumentation and Controls		10 % of Purchased Equipment Cost			18,509
Construction and Installation		30 % of Purchased Equipment Cost			55,528
Treatment System Building		sq feet	27	1,200	32,400
Installation Subtotal					**$161,965**
Total Capital Cost					**$347,058**

Source: Arthur D. Little, Inc.

4.2.9.9 Operating Cost. The annual operating cost for the GAC primary treatment system is approximately \$0.29 million, as presented in Table 4.2.9-2. Using the annual operating cost, the net present value was calculated for the 30-year scenario using a 5% and a 10% interest rate.

		5% Interest Rate		10% Interest Rate	
Time Frame	**Annual Cost**	**Discount Factor**	**NPV**	**Discount Factor**	**NPV**
1-30 years	\$0.29M	15.8	\$4.6M	9.9	\$2.9M

The carbon purchase and carbon disposal represent the largest operating costs for this alternative. If the flow rate or the contaminant concentration in the inlet to the GAC system was increased by 50% carbon usage would also increase by 50%. This increase in carbon usage would increase the operating costs from \$290,000 to \$330,000, and the 5% NPV would increase from \$4.6 million to \$5.2 million.

4.2.9.10 NCP Evaluation Criteria. The degree to which GAC adsorption of the contaminated ground water meets the NCP evaluation criteria is discussed below.

Overall Protection of Human Health and the Environment

This alternative would return the ground water to its potential beneficial use within 30 years. Upon achieving the remedial action objectives, the total hazard index for the ingestion of ground water for all compounds, at reasonable maximum exposure, would be reduced from 60 to 2. The total incremental cancer risk for the ingestion of ground water for all compounds at reasonable maximum exposure would be reduced from 2×10^{-3} to 3×10^{-4} (see Section 2.1, Remedial Action Objectives).

Unlike the UV/oxidation alternatives this alternative would not provide treatment for the contamination on site. The spent GAC would be sent off site for thermal destruction. The alternative would not pose a short-term risk to human health or the environment and would maximize the amount of water that was returned to the aquifer.

Compliance with ARARs

The alternative would not meet the preliminary remediation goals in 30 years but would achieve an incremental carcinogenic risk of 10^{-4} and a hazard index of 1. The alternative would meet all action-specific ARARs, including:

- No state and federal safe drinking water regulations exist for the contaminants of concern; therefore, the extracted ground water will be treated to ensure that each compound meets a hazard index equal to or less than 1, an excess cancer risk of greater than 10^{-6}, or the analytical detection limit prior to its return to the aquifer.

Table 4.2.9-2: Annual Operating Cost for Granular Activated Carbon - Alternative 6A

Item	Units	Units/ Year	Unit Cost (1993 Dollars)	Annual Cost (1993 Dollars)
Variable Cost				
Monitoring				
Sample Collection	hours	640	30	19,200
Supervision	hours	32	50	1,600
Sample Analysis	samples	152	150	22,800
Data Review and Reporting	hours	32	65	2,080
Five-Year Review (a)	hours	50	80	4,000
Electrical (b)	kw/yr	321,825	0.06	19,310
Granular Activated Carbon				
GAC Bed - 2000 lbs	Ton	13.2	4500	59,400
GAC Incineration (c)				
Polyethylene Lined Drums	Drum	79	25	1,975
Shipping	Drum	79	60	4,740
Treatment/Disposal	Drum	79	420	33,180
Operational Monitoring	samples	100	150	15,000
Labor				
Operator (d)	hours	2,500	30	75,000
Supervisor (e)	hours	200	50	10,000
Variable Cost Subtotal				**$268,285**
Fixed Cost				
Maintenance				
Labor and Materials	7% of Capital Investment			24,290
Fixed Cost Subtotal				**$24,290**
Total Annual Operating Cost				**$292,575**

Notes:
(a) – The cost for the Five-Year Review has been divided evenly over five years
(b) – Electrical includes power for pumps, and misc. electrical
for heating building, lighting, etc.
(c) - Assumes 335 pounds of dewatered GAC/55 gallon drum
(d) – Two operators on-site 3.0 days/week
(e) – One supervisor 4 hours/week to review operation of process

Source: Arthur D. Little, Inc.

- State surface water discharge or underground injection regulations on the disposal of the treated ground water.

- All RCRA requirements will be met in regard to the transport and disposal of the residuals from the treatment process. The explosive concentration in the spent carbon will be equal to or less than 7%, which is well below the explosive limit of 10% (Arthur D. Little, 1987). A TCLP analysis of the spent GAC would have to be performed to ensure that the DNT concentration was below the RCRA limit.

Long-Term Effectiveness

The residual risk that would remain on site due to contamination in the ground water would be reduced to a hazard index of 2 and a carcinogenic risk of 3×10^{-4} in 30 years. Without active contamination treatment, the risk reduction would not be reached for an estimated 330 years.

Treatment residuals that are generated during the remediation of the ground water would be disposed of in a manner to eliminate unacceptable risks. The contaminants adsorbed to the spent GAC would be destroyed by incineration or by another type of thermal treatment (e.g, regeneration or a cement kiln). Any free product removed from the equalization tank would be shipped off site for treatment and disposal.

The alternative would be operated until the ground water met the stated cleanup levels for the alternative, and the contaminants would be destroyed when the carbon is incinerated or by another type of thermal treatment (e.g, regeneration or a cement kiln). Therefore, no long-term controls would be necessary. All the technologies that would be used in this alternative are considered reliable.

This alternative would require five-year reviews to evaluate whether the alternative is protective of public health and the environment. The five-year reviews would be initiated five years after the start of the remedial action and would continue until no contaminants remain at the site above levels that allow for unrestricted use and unlimited exposure.

Reduction of Toxicity, Mobility, or Volume Through Treatment

The contamination adsorbed on the GAC will be irreversibly destroyed by incineration of the carbon or by another type of thermal treatment (e.g, regeneration or a cement kiln). This treatment system will reduce the volume, toxicity, and mobility of the contaminants.

The primary GAC treatment system will generate approximately 13.2 tons/year of spent carbon for off-site incineration. In addition to the spent GAC, an estimated 50 pounds of sediment will be collected each year in the equalization tank. This sediment will be analyzed and disposed of off site if found to be free of contamination.

Short-Term Effectiveness

The operation of the GAC treatment system is not expected to increase the risk to the community or the environment because the contaminants will be adsorbed on the GAC and irreversibly destroyed by incineration. The risks to the workers and the environment from using the GAC would be minimized through the operational limit of 0.07 pounds contaminant per pound of GAC, which should allay concerns regarding potential explosivity of the contaminated GAC.

The alternative would meet a carcinogenic risk of 10^{-4} and a hazard index of 1 within 30 years. If no active remediation alternative is implemented at the site, the ground water will not meet the remedial action objectives for an estimated 330 years.

Implementation

The construction and operation of the GAC system can be easily implemented and is technically capable of treating the contaminants in the ground water. The capacity of the system can be increased if additional ground water needs to be treated or the concentration of contamination is greater than expected.

There is some uncertainty surrounding the reinfiltration of treated ground water into the lagoons to flush the remaining contaminants from the soils. Because there is the potential for the reinfiltration spreading the contamination, the ground water in the vicinity of the lagoons will have to be monitored to ensure that reinfiltration is not adversely affecting the ability to remediate the ground water. If there is a concern, then the ground water will be switched to the reinfiltration galleys upgradient.

No special equipment, materials, or technical specialists would be required for the implementation of the GAC system. Vendors are also currently available for the supply and incineration of the GAC.

State and local coordination would be required for the implementation of legal restrictions on the use of ground water at the site and the discharge of treated ground water to the environment.

Cost

The capital and operating costs are presented in Section 4.2.9.8 and Section 4.2.9.9, respectively.

4.2.10 Alternative 6B - Carbon Adsorption (10 Years, Remediated to a Carcinogenic Risk of 1×10^{-4} and a Hazard Index of 1)

In this alternative, the ground water will be extracted from a series of three wells over a 10-year period to remediate the ground water to 77 µg/L for RDX and 18 µg/L for TNT (risk-based cleanup level at 1×10^{-4} and a hazard index of 1, respectively). The extracted water will be treated with activated carbon to remove the explosives from the water stream (see Section 4.2.5.6, GAC Primary Treatment).

After the ground water has been treated to meet risk-based cleanup levels, the treated ground water will initially be pumped to the explosive washout lagoons where it will be allowed to reinfiltrate into the soils under the lagoons. Reinfiltration of the treated ground water into the lagoons will flush the remaining soil contamination into the ground water table where it will be collected downgradient in the extraction wells. After approximately 6 months the reinfiltration of the treated ground water will be moved to infiltration galleys 400 to 800 feet upgradient of the lagoons.

The GAC option would be designed to handle the same ground water flow rates and contaminant concentrations as the UV/oxidation system described in Section 4.2.4, Alternative 5B, and depicted in Figure 4.2.4-1. The spent carbon from the GAC treatment beds would be incinerated off site at any of the commercial hazardous waste incinerators described in Section 4.2.5.6 or treated using another type of thermal treatment; each of the incinerators listed in this section is capable of treating the spent carbon from this treatment system. Regeneration of the spent carbon contaminated with explosives is not feasible due to the destruction of carbon particles during regeneration; however, if regeneration becomes technically feasible, then regeneration of the carbon will be considered during the remedial action.

In addition, this alternative will require ground water monitoring, five-year reviews, and institutional controls, which will continue until the contamination has been remediated to the detection limits stated above.

4.2.10.1 Institutional Controls. While the ground water is being remediated, institutional controls will be needed to restrict access to the contaminated aquifer, the contaminated ground water remediation equipment and the interconnecting piping. The level of institutional controls is similar to that previously discussed in Section 4.2.2, Alternative 2, and will not be repeated here.

4.2.10.2 Monitoring. The monitoring program would sample the existing monitoring wells and is identical to the program presented in Section 4.2.2.2, Monitoring, for the Institutional Control Alternative.

4.2.10.3 Five-Year Reviews. In addition to the monitoring of the ground water and the institutional controls, this alternative would also require five-year reviews intended to evaluate whether the alternative remains protective of public health and the environment. The five-year reviews would be initiated five years after the start of the remedial action and continue until no contaminants remain at the site above levels that allow for unrestricted use and unlimited exposure. These reviews would be identical to the reviews described for the No Action alternative (see the introduction to Section 4.2, Individual Analysis of Alternatives).

4.2.10.4 Ground Water Extraction. The extraction method for this ground water alternative would be identical to the extraction method described for Alternative 3A (see Section 4.2.3.4, Ground Water Extraction), except that the total pumping rate would be 200 gallons per minute (gpm). Figure 4.2.8-1 presents the extraction well locations and the predicted ground water capture zone when the extraction wells are operating. Intermediate (5 years) and final (30 years) contour maps are presented in Figures 4.2.8-2 to 4.2.8-5. These figures, along with the capture zone, demonstrate that this alternative will remediate the site and capture the reinfiltrated ground water.

4.2.10.5 Equalization. The equalization method for this ground water alternative would be identical to the equalization method described for Alternative 3A (see Section 4.2.3.5, Equalization), except that extracted ground water would be pumped to a 10,000-gallon equalization tank that would provide an approximately 50 minute retention time.

4.2.10.6 GAC Primary Treatment. The GAC treatment method for this ground water alternative would be identical to the GAC treatment method described for Alternative 4A (see Section 4.2.5.6, GAC Primary Treatment), except that the volume of GAC required on a daily basis for the flow rate for this alternative would be approximately 185 pound GAC per day. Therefore, each carbon bed would last approximately 11 days (see Appendix C) before being removed for incineration.

The off-site incineration method for this alternative would be identical to the method described in Section 4.2.3.6, GAC Primary Treatment, and will not be repeated here.

4.2.10.7 Reinfiltration. The reinfiltration method for this alternative would consist of a reinfiltration galley identical to that described for Alternative 5B (see Section 4.2.8.8, Reinfiltration). A description of the reinfiltration process will not be repeated here.

4.2.10.8 Capital Cost. The capital cost for the GAC primary treatment system is approximately $0.45 million, as presented in Table 4.2.10-1. The capital cost for the GAC system is spread out fairly evenly between all the unit operations. A moderate increase in the flow rate or the concentration of contaminants in the inlet would not require a larger GAC system. The capital cost would also be increased if the number of

Table 4.2.10-1: Capital Cost for Granular Activated Carbon – Alternative 6B

Item No.	Item	Units	Unit Cost (1993 $)	# of Units	Total Cost (1993 $)
100	**Extraction**				
101	GW Wells - 8 inch, 155 feet	Well	30,000	3	90,000
102	GW Well Pumps - 200 gpm, 5 hp	Pump	2,200	3	6,600
103	GW Buried Pipeline	Pipeline/500 ft	4,250	6	25,500
200	**Equalization**				
201	Equalization/Settling - 10,000 gal	Tank	25,400	1	25,400
202	Feed Pump - 250 gpm, 5 hp	Pump	2,300	2	4,600
300	**Granular Activated Carbon**				
301	GAC Tank - 2000 gal	Tank	4,250	2	8,500
302	GAC - 2000 lb	Bed	4,500	2	9,000
303	Discharge Pump - 250 gpm, 7 hp	Pump	2,500	2	5,000
400	**Reinfiltration Galley**				
401	Excavation	C.Y.	2	1,326	2,984
402	Crushed Stone	C.Y.	19	441	8,423
403	Backfill	C.Y.	2	132	222
404	Infilltration Galley	Galley	200	203	40,600
500	**Lagoon Lining**				
501	HDPE Liner	Lagoon	3,000	2	6,000
502	Crushed Stone	C.Y.	19	520	9,932
Equipment Subtotal					**$242,760**
Remedial Design / Planning		10 % of Purchased Equipment Cost			24,276
Plumbing		10 % of Purchased Equipment Cost			24,276
Electrical		10 % of Purchased Equipment Cost			24,276
Instrumentation and Controls		10 % of Purchased Equipment Cost			24,276
Construction and Installation		30 % of Purchased Equipment Cost			72,828
Treatment System Building		sq feet	27	1,200	32,400
Installation Subtotal					**$202,332**
Total Capital Cost					**$445,093**

Source: Arthur D. Little, Inc.

extraction wells needed to be increased to ensure that the capture zone was maintained; if the number of wells was doubled the total capital cost would only be increased by approximately $175,000.

4.2.10.9 Operating Cost. The annual operating cost for the GAC primary treatment system is approximately $0.48 million as presented in Table 4.2.10-2. Using the annual operating cost, the NPV was calculated for the 7-year scenario using a 5% and a 10% interest rate.

		5% Interest Rate		10% Interest Rate	
Time Frame	**Annual Cost**	**Discount Factor**	**NPV**	**Discount Factor**	**NPV**
1-10 years	$0.48M	7.9	$3.8M	6.0	$2.9M

The carbon purchase and carbon disposal represent the largest operating costs for this alternative. If the flow rate or the contaminant concentration in the inlet to the GAC system was increased by 50% carbon usage would also increase by 50%. This increase in carbon usage would increase the operating costs from $480,000 to $600,000, and the 5% NPV would increase from $3.8 million to $4.8 million.

4.2.10.10 NCP Evaluation Criteria. The degree to which GAC primary treatment of the contaminated ground water meets the NCP evaluation criteria is discussed below.

Overall Protection of Human Health and the Environment

This alternative would return the ground water to its potential beneficial use within 10 years. Upon achieving the remedial action objectives, the total hazard index for the ingestion of ground water for all compounds, at reasonable maximum exposure, would be reduced from 60 to 2. The total incremental cancer risk for the ingestion of ground water for all compounds at reasonable maximum exposure would be reduced from $2x10^{-3}$ to $3x10^{-4}$ (see Section 2.1 Remedial Action Objectives).

Unlike the UV/oxidation alternatives this alternative would not provide treatment for the contamination on site. The spent GAC would be sent off site for thermal destruction. The alternative would not pose a short-term risk to human health or the environment and would maximize the amount of water that was returned to the aquifer.

Compliance with ARARs

The alternative would not meet the preliminary remedial goals in ten years but would achieve an incremental carcinogenic risk of 10^{-4} and a hazard index of 1. The alternative would meet all action-specific ARARs, including:

Table 4.2.10-2: Annual Operating Cost for Granular Activated Carbon - Alternative 6B

Item	Units	Units/ Year	Unit Cost (1993 Dollars)	Annual Cost (1993 Dollars)
Variable Cost				
Monitoring				
Sample Collection	hours	640	30	19,200
Supervision	hours	32	50	1,600
Sample Analysis	samples	152	150	22,800
Data Review and Reporting	hours	32	65	2,080
Five-Year Review (a)	hours	50	80	4,000
Electrical (b)	kw/yr	474,305	0.06	28,458
Granular Activated Carbon				
GAC Bed - 2000 lbs	Ton	33.9	4500	152,550
GAC Incineration (c)				
Polyethylene Lined Drums	Drum	202	25	5,050
Shipping	Drum	202	125	25,250
Treatment/Disposal	Drum	202	420	84,840
Operational Monitoring	samples	100	150	15,000
Labor				
Operator (d)	hours	2,500	30	75,000
Supervisor (e)	hours	200	50	10,000
Variable Cost Subtotal				$445,828
Fixed Cost				
Maintenance				
Labor and Materials	7% of Capital Investment			31,160
Fixed Cost Subtotal				$31,160
Total Annual Operating Cost				$476,988

Notes:
(a) – The cost for the Five-Year Review has been divided evenly over five years
(b) – Electrical includes power for pumps, and misc. electrical
for heating building, lighting, etc.
(c) - Assumes 335 pounds of dewatered GAC/55 gallon drum
(d) – Two operators on-site 3.0 days/week
(e) – One supervisor 4 hours/week to review operation of process

Source: Arthur D. Little, Inc.

- No state and federal safe drinking water regulations exist for the contaminants of concern; therefore, the extracted ground water will be treated to ensure that each compound meets a hazard index equal to or less than 1, an excess cancer risk of greater than 10^{-6}, or the analytical detection limit prior to its return to the aquifer.

- State surface water discharge or underground injection regulations on the disposal of the treated ground water.

- All RCRA requirements will be met in regard to the transport and disposal of the residuals from the treatment process. The explosive concentration in the spent carbon will be equal to or less than 7%, which is well below the explosive limit of 10% (Arthur D. Little, 1987). A TCLP analysis of the spent GAC would have to be performed to ensure that the DNT concentration was below the RCRA limit.

Long-Term Effectiveness

The residual risk that would remain on site due to contamination in the ground water would be reduced to a hazard index of 2 and a carcinogenic risk of 3×10^{-4} in 10 years. Without active contamination treatment, the risk reduction would not be reached for an estimated 330 years.

Treatment residuals that are generated during the remediation of the ground water would be disposed of in a manner to eliminate unacceptable risks. The contaminants adsorbed on the spent GAC would be destroyed by incineration or by another type of thermal treatment (e.g., regeneration or a cement kiln). Any solids removed from the equalization tank would be shipped off site for treatment and disposal.

The alternative would be operated until the ground water met the cleanup levels associated with this alternative, and the contaminants would be destroyed when the spent carbon is incinerated or by another type of thermal treatment (e.g., regeneration or a cement kiln). Therefore, no long-term controls would be necessary. All the technologies that would be used in this alternative are considered reliable.

This alternative would require five-year reviews to evaluate whether the alternative is protective of public health and the environment. The five-year reviews would be initiated five years after the start of the remedial action and would continue until no contaminants remain at the site above levels that allow for unrestricted use and unlimited exposure.

Reduction of Toxicity, Mobility, or Volume Through Treatment

The GAC treatment system would irreversibly destroy the contaminants by incineration of the spent carbon or by another type of thermal treatment (e.g., regeneration or a cement kiln). This treatment system will reduce the volume, toxicity, and mobility of the contaminants.

The primary GAC treatment system will generate approximately 34 tons/year of spent carbon for off-site incineration. In addition to the spent GAC, an estimated 150 pounds of sediment will be collected each year in the equalization tank; the sediment will be analyzed and disposed of off site if found to be free of contamination.

Short-Term Effectiveness

The operation of the primary GAC treatment system is not expected to increase the risk to the community or the environment because the contaminants will be adsorbed on the GAC and irreversibly destroyed by incineration of the spent GAC. The risks to the workers and the environment from using the GAC would be minimized through the use of operational limits on the allowed carbon capacity, as well as engineering controls and personal protective equipment.

The alternative would meet a carcinogenic risk of 10^{-4} and a hazardous index of 1 within 10 years. If no active remediation alternative is implemented at the site, the ground water will not meet the remedial action objectives for an estimated 330 years.

Implementation

The construction and operation of the primary GAC treatment system can be easily implemented and is technically capable of treating the contaminants in the ground water. The capacity of the system can be increased if additional ground water needs to be treated or the concentration of contamination is greater than expected.

There is some uncertainty surrounding the reinfiltration of treated ground water into the lagoons to flush the remaining contaminants from the soils. Because there is the potential for the reinfiltration spreading the contamination, the ground water in the vicinity of the lagoons will have to be monitored to ensure that reinfiltration is not adversely affecting the ability to remediate the ground water. If there is a concern, then the ground water will be switched to the reinfiltration galleys upgradient.

No special equipment, materials, or technical specialists would be required for the implementation of the GAC treatment system. Vendors are also currently available for the supply and incineration of the GAC.

State and local coordination would be required for the implementation of legal restrictions on the use of ground water at the site and the discharge of treated ground water to the environment.

Cost
The capital and operating costs are presented in Section 4.2.10.8 and Section 4.2.10.9, respectively.

4.3 Comparative Analysis of Alternatives

The comparative analysis of the six alternatives is presented below for each of the NCP evaluation criteria.

4.3.1 Protection of Human Health and the Environment

Alternatives 3A and 3B (UV/oxidation treatment) would reduce the contamination in the ground water to below preliminary remediation goals in a time frame of 30 and 10 years, respectively. Alternatives 4A and 4B (GAC adsorption) would also reduce the contamination in the ground water to below preliminary remedial goals in the same time frames of 30 and 10 years, respectively.

Alternatives 5A and 5B (UV/oxidation treatment) would not reduce the contamination in the ground water to below the preliminary remediation goals but would reduce the explosive concentrations to an incremental cancer risk of 10^{-4} and a hazard index of 1 in a 30- or 10-year time frame, respectively. Alternatives 6A and 6B (GAC adsorption) would also reduce the explosive concentrations to levels that yield a resultant incremental cancer risk of 10^{-4} and a hazard index of 1 in a 30- or 10-year time frame, respectively. The ability to meet the time frames presented in these alternatives is dependent on two factors:

- The ability to extract the contaminated ground water from the aquifer
- The ability of the alternative to effectively destroy or remove the contaminants of concern from the ground water

Upon achieving the remedial action objectives for Alternatives 3A, 3B, 4A and 4B, the total hazard index for the ingestion of and dermal contact with ground water for all compounds, at reasonable maximum exposure, would be reduced from 60 to approximately 2. The total incremental cancer risk for the ingestion of ground water for all compounds, at reasonable maximum exposure, would be reduced from 2×10^{-3} to 1.3×10^{-5}. Similarly, upon achieving the remedial action objectives for Alternatives 5A, 5B, 6A, and 6B, the total hazard index for the ingestion of ground water for all compounds at reasonable maximum exposure would be reduced from 60 to approximately 2, and the total incremental cancer risk for the ingestion of ground water for all compounds, at reasonable maximum exposure would be reduced from 2×10^{-3} to 3×10^{-4}. For Alternatives 4A, 4B, 6A, and 6B, only the explosive contamination would be remediated. The naturally occurring metal contamination would remain in the aquifer at current levels and accounts for most of the remaining cancer risk.

Each of the eight pump and treat options (Alternatives 3A, 3B, 4A, 4B, 5A, 5B, 6A and 6B) would have the extracted ground water reinfiltrated into the aquifer to eliminate the potential for lowering the level of the water table. Reinfiltration galleys or reinjection wells would have to be carefully designed and located to prevent the migration of contaminants away from the extraction wells. In addition, each of these alternatives would include an initial discharge of treated ground water into the washout lagoons to flush the remaining contamination from the soil. Because of the uncertainty surrounding the flushing of the explosive contaminants from the soil into the ground water, a detailed monitoring program will be required in order to ensure the reinfiltration is not spreading the contamination. If the reinfiltration causes an adverse effect on the aquifer, it will be stopped and the water will be sent to the reinfiltration galleys upgradient.

Alternative 1 (No Action) would not provide any protection of human health and the environment and would not return the aquifer to its beneficial use in a reasonable time frame. The implementation of the alternative would not have any beneficial impact on the environment.

Alternative 2 (Institutional Controls) would provide only limited protection of human health and the environment by restricting access to the contaminated ground water. Institutional Controls like the No Action alternative would not return the aquifer to its beneficial use in a reasonable time frame. The implementation of the alternative would not have any beneficial impact on the environment.

4.3.2 Compliance with ARARs

There are no chemical-specific ARARs for the explosive contamination; however, Alternatives 3A and 4A, and 3B and 4B would meet the preliminary remediation goals in the ground water in a reasonable time frame of 30 and 10 years, respectively, by extracting, treating and reinjecting the treated ground water back into the aquifer. Alternatives 5A, 5B, 6A, and 6B would reduce the contamination in the aquifer but they would not meet the chemical-specific ARARs for RDX and 2,4,6-TNT because these contaminants would only be reduced to an incremental cancer risk of $1x10^{-4}$ or a hazard index of 1. Alternatives 1 (No Action) and 2 (Institutional Controls) will take approximately 5,000 years to meet the preliminary remediation goals and return the ground water in the region to its beneficial use.

Alternatives 1 and 2 do not have any action-specific ARARs because no remedial action would be taken under these alternatives. Alternatives 3A through 6B would each meet the action-specific ARARs, including:

- No state and federal safe drinking water regulations exist for the contaminants of concern; therefore, the ground water will be treated to ensure that each compound meets a hazard index of 1 and an excess cancer risk of 10^{-6} prior to its return to the aquifer.

- State surface water discharge or underground injection regulations on the disposal of the treated ground water.

- All RCRA requirements will be met in regard to the transport and disposal of the residuals from the treatment process. The explosive concentration in e spent carbon will be equal to or less than 7%, which is well below the explosive limit of 10% (Arthur D. Little, 1987). TCLP analysis of the spent GAC would have to be performed to ensure that the DNT concentration was below the RCRA limit.

4.3.3 Long-Term Effectiveness

Alternatives 3A and 4A, and 3B and 4B would reduce the contamination in the ground water to below preliminary remediation goals in a time frame of either 30 (3A and 4A) or 10 (3B and 4B) years. Alternatives 5A, 5B, 6A, and 6B would not reduce the contamination in the ground water to below the preliminary remediation goals but would reduce the explosive concentrations to an incremental cancer risk of 1×10^{-4} or a hazard index of 1. The ability to meet the time frames presented in these alternatives is dependent on two factors:

- The ability to extract the contaminated ground water from the aquifer
- The ability of the alternative to effectively destroy or remove the contaminants of concern from the ground water

Upon achieving the remedial action objectives for Alternatives 3A, 3B, 4A, and 4B, the total hazard index for the ingestion of and dermal contact with ground water for all compounds, at reasonable maximum exposure, would be reduced from 60 to less than 2; and the total incremental cancer risk for the ingestion of ground water for all compounds at reasonable maximum exposure would be reduced from 2×10^{-3} to 1.3×10^{-5}. Similarly, upon achieving the remedial action objectives for Alternatives 5A, 5B, 6A, and 6B, the total hazard index for the ingestion of ground water for all compounds, at reasonable maximum exposure, would be reduced from 60 to approximately 2; and the total incremental cancer risk for the ingestion of ground water for all compounds, at reasonable maximum exposure, would be reduced from 2×10^{-3} to 3×10^{-4}. In all cases, the remaining risks would be due to the remaining explosive contamination.

Alternatives 3A through 6B would produce varying quantities and types of treatment residuals that would have to treated and disposed of off site. All residuals generated during the remediation of the ground water would be disposed of in a manner to eliminate unacceptable risks. The metal hydroxide sludges from the metal precipitation unit would be disposed of in a hazardous waste landfill (Alternatives 3 and 5); and the spent carbon from the GAC units would be incinerated off site or by another method of thermal treatment such as regeneration or a cement kiln (Alternatives 3 through 6). Alternatives 1 and 2 would not produce any residuals because no treatment would be performed.

Alternatives 3A, 3B, 4A, and 4B would be operated until the ground water met the preliminary remediation goals, and the contaminants would be either destroyed on site in the UV/oxidation system or off site when the carbon is incinerated (or treated by another method of thermal treatment); therefore, no long-term controls would be necessary. Alternatives 5A, 5B, 6A, and 6B, however, would leave residual RDX and 2,4,6-TNT contamination in the ground water at an incremental cancer risk of 1×10^{-4} for each contaminant.

All the technologies that would be used in these alternatives are considered reliable. However, the UV/oxidation pilot study found that UV/oxidation could not economically meet preliminary remedial goals without GAC used as a polishing unit, with off-site thermal treatment of the spent carbon.

All six alternatives would require five-year reviews to evaluate whether the alternative is protective of public health and the environment. The five-year reviews would be initiated five years after the start of the remedial action and would continue until no contaminants remain at the site above levels that allow for unrestricted use and unlimited exposure.

4.3.4 Reduction of Toxicity, Mobility, or Volume through Treatment

Alternatives 1 and 2 would allow the contaminated region to naturally attenuate. The natural attenuation would not reduce the toxicity, mobility, or volume of the contamination by treatment; however, the reduction of the contamination would occur by natural means (biological, abiotic, and diffusion) over a 5,000-year period.

In Alternatives 3A, 3B, 5A, and 5B, the UV/oxidation system would remove approximately 90% of the contamination from the extracted ground water, based on pilot-scale treatability studies (ICF Kaiser Engineers, 1993) and an economic analysis. The remaining contaminants would be adsorbed using the GAC polishing system.

The UV/oxidation system would irreversibly destroy the contaminants directly by oxidizing the organics to carbon dioxide, water, and nitrates. The residual contaminants would adsorb onto the GAC. The contamination adsorbed on the GAC would then be irreversibly destroyed by thermal treatment at an off-site facility. Both treatment systems will reduce the volume, toxicity, and mobility of the contaminants.

In Alternatives 4A, 4B, 6A, and 6B, the primary GAC treatment system would remove greater than 99% of the contamination from the extracted ground water, based on previously conducted adsorption studies (ICF Kaiser Engineers, 1993). The adsorbed contaminants would be irreversibly destroyed when the spent GAC is incinerated or treated using another type of thermal treatment such s regeneration or a cement kiln.

Alternatives 3A through 6B would produce varying quantities and types of treatment residuals. The metal precipitation system for Alternatives 3A, 3B, 5A, and 5B will generate metal hydroxide sludges at a rate of approximately 185, 455, 107, and 273 tons/year respectively. These sludges will be disposed of off site as a hazardous waste. The spent GAC will be generated at a rate of approximately 1 to 6 tons/year for any of the UV/oxidation alternatives (Alternatives 3 and 5), and approximately 23 tons/yr for Alternatives 4A, 56 tons/year for Alternative 4B, 13 tons/year for Alternative 6A, and 34 tons/year for Alternative 6B. Residual GAC will be thermally treated off site. Alternatives 1 and 2 would not produce any residuals because no treatment would be performed.

4.3.5 Short-Term Effectiveness

The operations of Alternatives 3A through 6B are not expected to increase the risk to the community since no contaminants will be released to the environment. The risks to the workers from using the acids, bases, and the ozone would be minimized through the use of engineering controls and personal protective equipment.

Alternatives 3A and 4A, and 3B and 4B will achieve long-term effectiveness in the ground water in the reasonable time frame of 30 and 10 years, by extracting, treating and reinjecting the treated ground water back into the aquifer. Alternatives 5A and 6A and 5B and 6B would reach their objective in 30 and 10 years, respectively; however, both of these alternatives would leave residual RDX and 2,4,6-TNT contamination in the ground water above the preliminary remedial goals. Alternatives 1 and 2 would take approximately 5,000 years to meet the long-term objective of returning the ground water in the region to its beneficial use.

The ability to meet the time frames presented in these alternatives is dependent on two factors:

- The ability to extract the contaminated ground water from the aquifer
- The ability of the alternative to effectively destroy or remove the contaminants of concern from the ground water

4.3.6 Implementation

The construction and operation of the UV/oxidation systems for Alternatives 3A, 3B, 5A, and 5B can be easily implemented and would be technically capable of treating the contaminants in the ground water. However, the UV/oxidation system is economically feasible only when used with a GAC polishing unit as previously explained in Section 4.2.3. The GAC systems specified for Alternatives 4A, 4B, 6A, and 6B can also be easily implemented and have been proven to be capable of providing adequate primary treatment. The processing capacity of the alternatives can be increased if additional ground water needs to be treated or the concentration of contamination is greater than expected. No special equipment, materials, or technical specialists would be required for the implementation of these remedial alternatives.

There is some uncertainty surrounding the reinfiltration of treated ground water into the lagoons to flush the remaining contaminants from the soils. Because there is the potential for the reinfiltration spreading the contamination, the ground water in the vicinity of the lagoons will have to be monitored to ensure that reinfiltration is not adversely affecting the ability to remediate the ground water. If there is a concern, then the ground water will be switched to the reinfiltration galleys upgradient.

Alternatives 2 through 6B would require state and local coordination for the implementation of legal restrictions on the use of ground water at the site and the discharge of treated ground water to the environment.

4.3.7 Cost. The capital and operating costs for each alternative is shown below:

Alternative	Capital Cost	Operating Cost	Total NPV
1	—	$4,000	$81,000 (a)
2	$20,000	$40,000	$820,000 (a)
3A	$2,200,000	$790,000	$14,700,000 (b)
3B	$3,700,000	$1,600,000	$16,300,000 (c)
4A	$400,000	$380,000	$6,400,000 (b)
4B	$550,000	$670,000	$5,800,000(c)
5A	$1,700,000	$550,000	$10,400,000(b)
5B	$2,900,000	$1,100,000	$11,600,000(c)
6A	$350,000	$290,000	$4,900,000(b)
6B	$450,000	$480,000	$4,200,000(c)

(a) Total NPV estimated over 300 years at an interest rate of 5%

(b) Total NPV estimated over 30 years at an interest rate of 5%.

(c) Total NPV estimated over 10 years at an interest rate of 5%.

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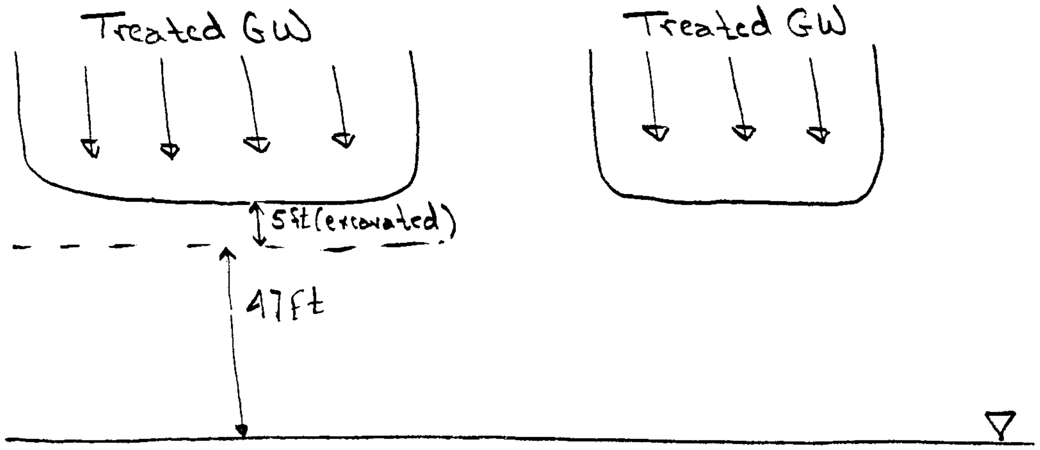
Appendix A: Explosive Contamination in Ground Water Reinfiltration

RDX+TNT in Soils under EWL | Nov. 22, 1993

Objective: Estimate the mass of TNT and RDX in Soils under the EWLs. Then estimate RDX and TNT concentration in flushing water when it reaches the ground water Table.



$$\text{Area of Lagoons} = (39\,ft + 27\,ft) \times 80\,ft = 5280\,ft^3$$

$$\text{Volume of Soil} = 5280\,ft^2 \times 47\,ft = 248{,}160\,ft^3 \times \frac{1\,CY}{27\,ft^3}$$
$$= 9{,}191\ yd^3$$

$$\text{Mass of Soil} = 9191\,yd^3 \times 1.3\,ton/yd^3 = 11{,}948\ tons \times 907.19\,kg/ton$$
$$= 10.8\ Mkg$$

$$\text{Mass of RDX in Soil} = 10.8\,Mkg \times \frac{20\ Mmg\ RDX}{Mkg} = 216\ Mmg\ RDX$$

$$\text{Mass of TNT in Soil} = 10.8\,Mkg \times \frac{12\ Mmg\ TNT}{Mkg} = 130\ Mmg\ TNT$$

Volume of Flushing Water over 1yr at 200 gpm =

$$200\,gal/min \times \frac{60\,min}{hr} \times \frac{24\,hr}{day} \times \frac{365\,days}{yr} \times \frac{3.78\,L}{gal}$$
$$= 398\,M\ liters/yr$$

$$\text{Avg. Concen. RDX in flushing Water} = 216\ Mmg\ RDX / 398\,M\ Liters = 0.5\ mg/L$$

$$\text{Avg Concen TNT} = 130\ Mmg\ TNT / 398\,M\ liters = 0.3\ mg/L$$

Appendix B: Soil Leaching Model Output

Attachment A

```
1    ***********************************************************************
     *
     *    0NE-DIMENSIONAL CONVECTIVE-DISPERSIVE EQUATION
     *
     *    FIRST-TYPE BOUNDARY CONDITION
     *    FINITE PROFILE
     *
     *    NO PRODUCTION OR DECAY
     *    LINEAR ADSORPTION (R)
     *    CONSTANT INITIAL CONCENTRATION (CI)
     *    INPUT CONCENTRATION = C0 (T.LE.T0)
     *                 = 0 (T.GT.T0)
     *
     *    RDX - Discharge Rate=77 gpm, Kd=0.21 ml/g
     *
     ***********************************************************************


     INPUT PARAMETERS
     ===============

     V =   428.0000        D =  67838.0000
     R =     2.5750        T0 =     .0000
     CI =109524.0000        C0 =     .0000
     XL =  1593.1900        TOL =  .000100


     CALCULATED EIGENVALUES
     =====================
      2.655507   5.456707   8.393501  11.410465  14.471429

     17.557554  20.658992  23.770310  26.888321  30.011057

     33.137243  36.266021  39.396792  42.529129  45.662717

     48.797318  51.932754  55.068884  58.205597  61.342804



 DISTANCE      TIME     PORE VOLUME    CONCENTRATION     NUMBER
   (X)          (T)        (VVO)            (C)         OF TERM
   1593          1         0.2687        109524.0           0
   1593          2         0.5374       **********         10
   1593          3         0.806        **********          8
   1593          4         1.0747       **********          8
   1593          5         1.3434         95012.3           8
   1593          6         1.6121         81818.3           6
   1593          7         1.8807         67333.3           6
   1593          8         2.1494         53521.6           6
   1593          9         2.4181         41454.8           6
   1593         10         2.6868         31496.7           6
   1593         11         2.9554         23590.2           6
   1593         12         3.2241         17479.6           6
   1593         13         3.4928         12847.1           6
   1593         14         3.7615          9384.3           6
   1593         15         4.0301          6822.5           6
```

```
1    ***********************************************************************
     *
     *    0NE-DIMENSIONAL CONVECTIVE-DISPERSIVE EQUATION
     *
     *    FIRST-TYPE BOUNDARY CONDITION
     *    FINITE PROFILE
     *
     *    NO PRODUCTION OR DECAY
     *    LINEAR ADSORPTION (R)
     *    CONSTANT INITIAL CONCENTRATION (CI)
     *    INPUT CONCENTRATION = C0 (T.LE.T0)
     *                 = 0 (T.GT.T0)
     *
     *    RDX - Discharge Rate=138 gpm, Kd=0.21 ml/g                     *
     *
     ***********************************************************************


     INPUT PARAMETERS
     ===============

     V =   767.0000        D = 121570.0000
     R =     2.5750        T0 =     .0000
     CI =109524.0000        C0 =     .0000
     XL =  1593.1900        TOL =  .000100


     CALCULATED EIGENVALUES
     =====================
      2.655505   5.456705   8.393500  11.410464  14.471428

     17.557553  20.658992  23.770309  26.888320  30.011056

     33.137242  36.266020  39.396792  42.529129  45.662716

     48.797318  51.932754  55.068883  58.205596  61.342804



 DISTANCE      TIME     PORE VOLUME    CONCENTRATION     NUMBER
   (X)          (T)        (VVO)            (C)         OF TERM
   1593          1         0.4815         109524           10
   1593          2         0.963         **********         8
   1593          3         1.4444        90358.0492         6
   1593          4         1.9259        64922.5782         6
   1593          5         2.4074        41894.4568         6
   1593          6         2.8889        25369.2774         6
   1593          7         3.3704        14794.8332         6
   1593          8         3.8519         8433.7398         6
   1593          9         4.3333         4740.4048         4
   1593         10         4.8148         2640.9782         4
   1593         11         5.2963         1463.0676         4
   1593         12         5.7778          807.5868         4
   1593         13         6.2593          444.7289         4
   1593         14         6.7407          244.5342         4
   1593         15         7.2222          134.3237         4
```

```
1    ***********************************************************************
     *
     *    0NE-DIMENSIONAL CONVECTIVE-DISPERSIVE EQUATION
     *
     *    FIRST-TYPE BOUNDARY CONDITION
     *    FINITE PROFILE
     *
     *    NO PRODUCTION OR DECAY
     *    LINEAR ADSORPTION (R)
     *    CONSTANT INITIAL CONCENTRATION (CI)
     *    INPUT CONCENTRATION = C0 (T.LE.T0)
     *                 = 0 (T.GT.T0)
     *
     *    RDX - Discharge Rate=200 gpm, Kd=0.21 ml/g                     *
     *
     ***********************************************************************


     INPUT PARAMETERS
     ===============

     V =  1111.0000        D = 176093.0000
     R =     2.5750        T0 =     .0000
     CI =109524.0000        C0 =     .0000
     XL =  1593.1900        TOL =  .000100


     CALCULATED EIGENVALUES
     =====================
      2.655508   5.456708   8.393503  11.410466  14.471430

     17.557554  20.658993  23.770310  26.888321  30.011057

     33.137243  36.266021  39.396793  42.529130  45.662717

     48.797319  51.932754  55.068884  58.205597  61.342805



 DISTANCE      TIME     PORE VOLUME    CONCENTRATION     NUMBER
   (X)          (T)        (VVO)            (C)         OF TERM
   1593         1.0        0.6974          109524           8
   1593         2.0        1.3949        92701.1317         6
   1593         3.0        2.0923        56335.7596         6
   1593         4.0        2.7897        28236.0097         6
   1593         5.0        3.4871        12931.4885         6
   1593         6.0        4.1846         5670.4951         4
   1593         7.0        4.882          2432.7732         4
   1593         8.0        5.5794         1031.9531         4
   1593         9.0        6.2768          435.1276         4
   1593        10.0        6.9743          182.887          4
   1593        11.0        7.6717           76.7363         4
   1593        12.0        8.3691           32.1674         4
   1593        13.0        9.0665           13.4776         4
   1593        14.0        9.764             5.6453         4
   1593        15.0       10.4614            2.3643         4
```

Attachment A

1593	16	4.2988	4942.0	4
1593	17	4.5675	3569.8	4
1593	18	4.8362	2573.0	4
1593	19	5.1048	1851.4	4
1593	20	5.3735	1330.3	4
1593	21	5.6422	955.0	4
1593	22	5.9109	684.9	4
1593	23	6.1795	491.0	4
1593	24	6.4482	351.7	4
1593	25	6.7169	251.9	4
1593	26	6.9856	180.3	4
1593	27	7.2542	129.1	4
1593	28	7.5229	92.4	4
1593	29	7.7916	66.1	4
1593	30	8.0603	47.3	4
1593	31	8.3289	33.8	4
1593	32	8.5976	24.2	4
1593	33	8.8663	17.3	4
1593	34	9.135	12.4	4
1593	35	9.4036	8.9	4
1593	36	9.6723	6.3	4
1593	37	9.941	4.5	4
1593	38	10.2097	3.2	4
1593	39	10.4783	2.3	4
1593	40	10.747	1.7	4
1593	41	11.0157	1.2	4
1593	42	11.2844	0.8	4
1593	43	11.553	0.6	4
1593	44	11.8217	0.4	4
1593	45	12.0904	0.3	4

1593	16	7.7037	73.7368	4
1593	17	8.1852	40.4606	4
1593	18	8.6667	22.1952	4
1593	19	9.1481	12.1733	4
1593	20	9.6296	6.6758	4
1593	21	10.1111	3.6607	4
1593	22	10.5926	2.0073	4
1593	23	11.0741	1.1006	4
1593	24	11.5556	0.6035	4
1593	25	12.037	0.3309	4

1593	16.0	11.1588	0.9901	4
1593	17.0	11.8562	0.4146	4
1593	18.0	12.5537	0.1736	4
1593	19.0	13.2511	0.0727	4
1593	20.0	13.9485	0.0304	4
1593	21.0	14.646	0.0127	4
1593	22.0	15.3434	0.0053	4
1593	23.0	16.0408	0.0022	4
1593	24.0	16.7382	0.0009	4
1593	25.0	17.4357	0.0004	4

Attachment B

```
1   **********************************************************************
    *
    *   0NE-DIMENSIONAL CONVECTIVE-DISPERSIVE EQUATION
    *
    *   FIRST-TYPE BOUNDARY CONDITION
    *   FINITE PROFILE
    *
    *   NO PRODUCTION OR DECAY
    *   LINEAR ADSORPTION (R)
    *   CONSTANT INITIAL CONCENTRATION (CI)
    *   INPUT CONCENTRATION = C0 (T.LE.T0)
    *                = 0 (T.GT.T0)
    *
    *   TNT - Discharge Rate=77 gpm, Kd=1.0 ml/g                         *
    *
    **********************************************************************

    INPUT PARAMETERS
    ================

    V =   428.0000         D =  67838.0000
    R =     8.5000        T0 =      .0000
    CI = 12000.0000        C0 =      .0000
    XL =  1593.1900       TOL =    .000100

    CALCULATED EIGENVALUES
    ======================
     2.655507   5.456707   8.393501  11.410465  14.471429

    17.557554  20.658992  23.770310  26.888321  30.011057

    33.137243  36.266021  39.396792  42.529129  45.662717

    48.797318  51.932754  55.068884  58.205597  61.342804


  DISTANCE     TIME    PORE VOLUME   CONCENTRATION    NUMBER
     (X)        (T)       (VVO)           (C)         OF TERM
    1593         1       0.2687         12000.0          0
    1593         2       0.5374         12000.0          0
    1593         3       0.806          12000.0          0
    1593         4       1.0747         12000.0         12
    1593         5       1.3434         12000.0         10
    1593         6       1.6121         11999.5         10
    1593         7       1.8807         11996.6         10
    1593         8       2.1494         11986.3         10
    1593         9       2.4181         11960.1          8
    1593        10       2.6868         11907.2          8
    1593        11       2.9554         11816.4          8
    1593        12       3.2241         11678.9          8
    1593        13       3.4928         11489.0          8
    1593        14       3.7615         11244.5          8
    1593        15       4.0301         10947.2          8
```

```
1   **********************************************************************
    *
    *   0NE-DIMENSIONAL CONVECTIVE-DISPERSIVE EQUATION
    *
    *   FIRST-TYPE BOUNDARY CONDITION
    *   FINITE PROFILE
    *
    *   NO PRODUCTION OR DECAY
    *   LINEAR ADSORPTION (R)
    *   CONSTANT INITIAL CONCENTRATION (CI)
    *   INPUT CONCENTRATION = C0 (T.LE.T0)
    *                = 0 (T.GT.T0)
    *
    *   TNT - Discharge Rate=138 gpm, Kd=1.0 ml/g                        *
    *
    **********************************************************************

    INPUT PARAMETERS
    ================

    V =   767.0000         D = 121570.0000
    R =     8.5000        T0 =      .0000
    CI = 12000.0000        C0 =      .0000
    XL =  1593.1900       TOL =    .000100

    CALCULATED EIGENVALUES
    ======================
     2.655505   5.456705   8.393500  11.410464  14.471428

    17.557553  20.658992  23.770309  26.888320  30.011056

    33.137242  36.266020  39.396792  42.529129  45.662716

    48.797318  51.932754  55.068883  58.205596  61.342804


  DISTANCE     TIME    PORE VOLUME   CONCENTRATION    NUMBER
     (X)        (T)       (VVO)           (C)         OF TERM
    1593         1       0.4815          12000           0
    1593         2       0.963         11999.9999        0
    1593         3       1.4444        11999.8862       10
    1593         4       1.9259        11995.5789       10
    1593         5       2.4074        11961.6049        8
    1593         6       2.8889         11842.96         8
    1593         7       3.3704        11582.246         8
    1593         8       3.8519        11150.2261        8
    1593         9       4.3333        10553.507         8
    1593        10       4.8148         9824.7445        6
    1593        11       5.2963         9008.4025        6
    1593        12       5.7778         8149.4421        6
    1593        13       6.2593         7286.723         6
    1593        14       6.7407         6450.3076        6
    1593        15       7.2222         5661.2496        6
```

```
1   **********************************************************************
    *
    *   0NE-DIMENSIONAL CONVECTIVE-DISPERSIVE EQUATION
    *
    *   FIRST-TYPE BOUNDARY CONDITION
    *   FINITE PROFILE
    *
    *   NO PRODUCTION OR DECAY
    *   LINEAR ADSORPTION (R)
    *   CONSTANT INITIAL CONCENTRATION (CI)
    *   INPUT CONCENTRATION = C0 (T.LE.T0)
    *                = 0 (T.GT.T0)
    *
    *   TNT - Discharge Rate=200 gpm, Kd=1.0 ml/g                        *
    *
    **********************************************************************

    INPUT PARAMETERS
    ================

    V =  1111.0000         D = 176093.0000
    R =     8.5000        T0 =      .0000
    CI = 12000.0000        C0 =      .0000
    XL =  1593.1900       TOL =    .000100

    CALCULATED EIGENVALUES
    ======================
     2.655508   5.456708   8.393503  11.410466  14.471430

    17.557554  20.658993  23.770310  26.888321  30.011057

    33.137243  36.266021  39.396793  42.529130  45.662717

    48.797319  51.932754  55.068884  58.205597  61.342805


  DISTANCE     TIME    PORE VOLUME   CONCENTRATION    NUMBER
     (X)        (T)       (VVO)           (C)         OF TERM
    1593        1.0      0.6974          12000           0
    1593        2.0      1.3949        11999.9319       10
    1593        3.0      2.0923        11989.5074       10
    1593        4.0      2.7897        11877.4119        8
    1593        5.0      3.4871        11493.5342        8
    1593        6.0      4.1846        10753.8819        8
    1593        7.0      4.882          9715.0766        6
    1593        8.0      5.5794         8505.8348        6
    1593        9.0      6.2768         7255.5902        6
    1593       10.0      6.9743         6060.7302        6
    1593       11.0      7.6717         4979.0866        6
    1593       12.0      8.3691         4036.9882        6
    1593       13.0      9.0665         3239.2033        6
    1593       14.0      9.764          2577.6387        6
    1593       15.0     10.4614         2037.6786        6
```

Attachment B

1593	16	4.2988	10601.2	8
1593	17	4.5675	10213.0	6
1593	18	4.8362	9790.1	6
1593	19	5.1048	9340.6	6
1593	20	5.3735	8872.4	6
1593	21	5.6422	8393.3	6
1593	22	5.9109	7909.9	6
1593	23	6.1795	7428.5	6
1593	24	6.4482	6954.0	6
1593	25	6.7169	6490.8	6
1593	26	6.9856	6042.2	6
1593	27	7.2542	5610.8	6
1593	28	7.5229	5198.6	6
1593	29	7.7916	4806.8	6
1593	30	8.0603	4436.3	6
1593	31	8.3289	4087.3	6
1593	32	8.5976	3759.9	6
1593	33	8.8663	3453.8	6
1593	34	9.135	3168.5	6
1593	35	9.4036	2903.2	6
1593	36	9.6723	2657.3	6
1593	37	9.941	2429.7	6
1593	38	10.2097	2219.6	6
1593	39	10.4783	2025.9	6
1593	40	10.747	1847.7	6
1593	41	11.0157	1684.0	6
1593	42	11.2844	1533.7	6
1593	43	11.553	1396.0	6
1593	44	11.8217	1270.0	6
1593	45	12.0904	1154.8	6
1593	46	12.3591	1049.5	6
1593	47	12.6277	953.4	6
1593	48	12.8964	865.7	6
1593	49	13.1651	785.8	6
1593	50	13.4338	713.0	6
1593	51	13.7024	646.8	4
1593	52	13.9711	586.5	4
1593	53	14.2398	531.8	4
1593	54	14.5085	482.0	4
1593	55	14.7772	436.7	4
1593	56	15.0458	395.7	4
1593	57	15.3145	358.4	4
1593	58	15.5832	324.5	4
1593	59	15.8519	293.9	4
1593	60	16.1205	266.0	4
1593	61	16.3892	240.8	4
1593	62	16.6579	217.9	4
1593	63	16.9266	197.2	4
1593	64	17.1952	178.4	4
1593	65	17.4639	161.4	4
1593	66	17.7326	146.0	4
1593	67	18.0013	132.1	4
1593	68	18.2699	119.5	4
1593	69	18.5386	108.1	4
1593	70	18.8073	97.7	4
1593	71	19.076	88.4	4
1593	72	19.3446	79.9	4

1593	16	7.7037	4932.6711	6
1593	17	8.1852	4271.3296	6
1593	18	8.6667	3679.2202	6
1593	19	9.1481	3154.9924	6
1593	20	9.6296	2695.1052	6
1593	21	10.1111	2294.7126	6
1593	22	10.5926	1948.3146	6
1593	23	11.0741	1650.2125	6
1593	24	11.5556	1394.8143	6
1593	25	12.037	1176.827	6
1593	26	12.5185	991.3666	6
1593	27	13	834.011	6
1593	28	13.4815	700.8136	6
1593	29	13.963	588.2921	4
1593	30	14.4444	493.4018	4
1593	31	14.9259	413.4994	4
1593	32	15.4074	346.3047	4
1593	33	15.8889	289.8599	4
1593	34	16.3704	242.4913	4
1593	35	16.8519	202.7732	4
1593	36	17.3333	169.4944	4
1593	37	17.8148	141.6289	4
1593	38	18.2963	118.3092	4
1593	39	18.7778	98.8032	4
1593	40	19.2593	82.4943	4
1593	41	19.7407	68.8635	4
1593	42	20.2222	57.4748	4
1593	43	20.7037	47.9622	4
1593	44	21.1852	40.0185	4
1593	45	21.6667	33.3864	4
1593	46	22.1481	27.8506	4
1593	47	22.6296	23.2305	4
1593	48	23.1111	19.3752	4
1593	49	23.5926	16.1586	4
1593	50	24.0741	13.4752	4
1593	51	24.5556	11.2368	4
1593	52	25.037	9.3697	4
1593	53	25.5185	7.8126	4
1593	54	26	6.514	4
1593	55	26.4815	5.431	4
1593	56	26.963	4.528	4
1593	57	27.4444	3.775	4
1593	58	27.9259	3.1472	4
1593	59	28.4074	2.6237	4
1593	60	28.8889	2.1873	4
1593	61	29.3704	1.8234	4
1593	62	29.8519	1.5201	4
1593	63	30.3333	1.2671	4
1593	64	30.8148	1.0563	4
1593	65	31.2963	0.8805	4

1593	16.0	11.1588	1602.3176	6
1593	17.0	11.8562	1254.6108	6
1593	18.0	12.5537	978.9753	6
1593	19.0	13.2511	761.7615	6
1593	20.0	13.9485	591.3935	4
1593	21.0	14.646	458.2747	4
1593	22.0	15.3434	354.5793	4
1593	23.0	16.0408	274.0046	4
1593	24.0	16.7382	211.5222	4
1593	25.0	17.4357	163.1498	4
1593	26.0	18.1331	125.7517	4
1593	27.0	18.8305	96.8703	4
1593	28.0	19.5279	74.5866	4
1593	29.0	20.2254	57.4064	4
1593	30.0	20.9228	44.169	4
1593	31.0	21.6202	33.9749	4
1593	32.0	22.3176	26.1277	4
1593	33.0	23.0151	20.0892	4
1593	34.0	23.7125	15.444	4
1593	35.0	24.4099	11.8713	4
1593	36.0	25.1073	9.1242	4
1593	37.0	25.8048	7.0121	4
1593	38.0	26.5022	5.3886	4
1593	39.0	27.1996	4.1407	4
1593	40.0	27.897	3.1816	4
1593	41.0	28.5945	2.4446	4
1593	42.0	29.2919	1.8782	4
1593	43.0	29.9893	1.443	4
1593	44.0	30.6868	1.1087	4
1593	45.0	31.3842	0.8518	4

Attachment B

1593	73	19.6133	72.2	4
1593	74	19.882	65.3	4
1593	75	20.1507	59.0	4
1593	76	20.4193	53.4	4
1593	77	20.688	48.2	4
1593	78	20.9567	43.6	4
1593	79	21.2254	39.4	4
1593	80	21.494	35.6	4
1593	81	21.7627	32.2	4
1593	82	22.0314	29.1	4
1593	83	22.3001	26.3	4
1593	84	22.5687	23.8	4
1593	85	22.8374	21.5	4
1593	86	23.1061	19.4	4
1593	87	23.3748	17.5	4
1593	88	23.6434	15.9	4
1593	89	23.9121	14.3	4
1593	90	24.1808	12.9	4
1593	91	24.4495	11.7	4
1593	92	24.7181	10.6	4
1593	93	24.9868	9.5	4
1593	94	25.2555	8.6	4
1593	95	25.5242	7.8	4
1593	96	25.7928	7.0	4
1593	97	26.0615	6.4	4
1593	98	26.3302	5.8	4
1593	99	26.5989	5.2	4
1593	100	26.8675	4.7	4
1593	101	27.1362	4.2	4
1593	102	27.4049	3.8	4
1593	103	27.6736	3.5	4
1593	104	27.9422	3.1	4
1593	105	28.2109	2.8	4
1593	106	28.4796	2.6	4
1593	107	28.7483	2.3	4
1593	108	29.0169	2.1	4
1593	109	29.2856	1.9	4
1593	110	29.5543	1.7	4

Attachment C

```
1  ***********************************************************************
   *
   *     ONE-DIMENSIONAL CONVECTIVE-DISPERSIVE EQUATION
   *
   *     FIRST-TYPE BOUNDARY CONDITION
   *     FINITE PROFILE
   *
   *     NO PRODUCTION OR DECAY
   *     LINEAR ADSORPTION (R)
   *     CONSTANT INITIAL CONCENTRATION (CI)
   *     INPUT CONCENTRATION = C0 (T.LE.T0)
   *                 = 0 (T.GT.T0)
   *
   *     RDX - Discharge Rate=77 gpm, Kd=1.05 ml/g                     *
   *
   ***********************************************************************


  INPUT PARAMETERS
  ================

  V =   428.0000        D =  67838.0000
  R =    12.8750       T0 =      .0000
  CI = 21900.0000       C0 =      .0000
  XL =  1593.1900       TOL =   .000100


  CALCULATED EIGENVALUES
  ======================
   2.655507   5.456707   8.393501  11.410465  14.471429

  17.557554  20.658992  23.770310  26.888321  30.011057

  33.137243  36.266021  39.396792  42.529129  45.662717

  48.797318  51.932754  55.068884  58.205597  61.342804


DISTANCE     TIME    PORE VOLUME   CONCENTRATION    NUMBER
  (X)         (T)       (VVO)           (C)         OF TERM
  1593         1        0.2687         21900            0
  1593         2        0.5374         21900            0
  1593         3        0.806          21900            0
  1593         4        1.0747         21900            0
  1593         5        1.3434         21900            0
  1593         6        1.6121       21899.999          0
  1593         7        1.8807       21899.9815        12
  1593         8        2.1494       21899.8399        10
  1593         9        2.4181       21899.1612        10
  1593        10        2.6868       21896.8414        10
  1593        11        2.9554       21890.7105        10
  1593        12        3.2241       21877.3077        10
  1593        13        3.4928       21851.947          8
  1593        14        3.7615       21809.0543         8
  1593        15        4.0301       21742.6666         8
```

```
1  ***********************************************************************
   *
   *     ONE-DIMENSIONAL CONVECTIVE-DISPERSIVE EQUATION
   *
   *     FIRST-TYPE BOUNDARY CONDITION
   *     FINITE PROFILE
   *
   *     NO PRODUCTION OR DECAY
   *     LINEAR ADSORPTION (R)
   *     CONSTANT INITIAL CONCENTRATION (CI)
   *     INPUT CONCENTRATION = C0 (T.LE.T0)
   *                 = 0 (T.GT.T0)
   *
   *     RDX - Discharge Rate=138 gpm, Kd=1.05 ml/g                    *
   *
   ***********************************************************************


  INPUT PARAMETERS
  ================

  V =   767.0000        D = 121570.0000
  R =    12.8750       T0 =      .0000
  CI = 21900.0000       C0 =      .0000
  XL =  1593.1900       TOL =   .000100


  CALCULATED EIGENVALUES
  ======================
   2.655505   5.456705   8.393500  11.410464  14.471428

  17.557553  20.658992  23.770309  26.888320  30.011056

  33.137242  36.266020  39.396792  42.529129  45.662716

  48.797318  51.932754  55.068883  58.205596  61.342804


DISTANCE     TIME    PORE VOLUME   CONCENTRATION    NUMBER
  (X)         (T)       (VVO)           (C)         OF TERM
  1593         1        0.4815         21900            0
  1593         2        0.963          21900            0
  1593         3        1.4444       21899.9999         0
  1593         4        1.9259       21899.9723        12
  1593         5        2.4074       21899.2091        10
  1593         6        2.8889       21892.7497        10
  1593         7        3.3704       21865.3246        10
  1593         8        3.8519       21789.6357         8
  1593         9        4.3333       21632.2822         8
  1593        10        4.8148       21362.9913         8
  1593        11        5.2963       20961.7503         8
  1593        12        5.7778       20421.6829         8
  1593        13        6.2593       19748.2803         8
  1593        14        6.7407       18956.5706         6
  1593        15        7.2222       18067.6498         6
```

```
1  ***********************************************************************
   *
   *     ONE-DIMENSIONAL CONVECTIVE-DISPERSIVE EQUATION
   *
   *     FIRST-TYPE BOUNDARY CONDITION
   *     FINITE PROFILE
   *
   *     NO PRODUCTION OR DECAY
   *     LINEAR ADSORPTION (R)
   *     CONSTANT INITIAL CONCENTRATION (CI)
   *     INPUT CONCENTRATION = C0 (T.LE.T0)
   *                 = 0 (T.GT.T0)
   *
   *     RDX - Discharge Rate=200 gpm, Kd=1.05 ml/g                    *
   *
   ***********************************************************************


  INPUT PARAMETERS
  ================

  V =  1111.0000        D = 176093.0000
  R =    12.8750       T0 =      .0000
  CI = 21900.0000       C0 =      .0000
  XL =  1593.1900       TOL =   .000100


  CALCULATED EIGENVALUES
  ======================
   2.655508   5.456708   8.393503  11.410466  14.471430

  17.557554  20.658993  23.770310  26.888321  30.011057

  33.137243  36.266021  39.396793  42.529130  45.662717

  48.797319  51.932754  55.068884  58.205597  61.342805


DISTANCE     TIME    PORE VOLUME   CONCENTRATION    NUMBER
  (X)         (T)       (VVO)           (C)         OF TERM
  1593         1        0.6974         21900            0
  1593         2        1.3949         21900            0
  1593         3        2.0923       21899.8924        10
  1593         4        2.7897       21895.1021        10
  1593         5        3.4871       21852.6409         8
  1593         6        4.1846       21691.6034         8
  1593         7        4.882        21315.2474         8
  1593         8        5.5794       20660.9237         8
  1593         9        6.2768       19721.3713         8
  1593        10        6.9743       18536.1636         6
  1593        11        7.6717       17171.2658         6
  1593        12        8.3691       15699.9783         6
  1593        13        9.0665       14190.1665         6
  1593        14        9.764        12697.7466         6
  1593        15       10.4614       11264.6829         6
```

Attachment C

1593	16	4.2988	21646.9819	8
1593	17	4.5675	21516.8437	8
1593	18	4.8362	21348.1059	8
1593	19	5.1048	21137.8543	8
1593	20	5.3735	20884.4928	8
1593	21	5.6422	20587.7173	8
1593	22	5.9109	20248.4077	8
1593	23	6.1795	19868.4671	8
1593	24	6.4482	19450.6349	8
1593	25	6.7169	18998.2917	8
1593	26	6.9856	18515.2722	6
1593	27	7.2542	18005.6944	6
1593	28	7.5229	17473.8098	6
1593	29	7.7916	16923.878	6
1593	30	8.0603	16360.0654	6
1593	31	8.3289	15786.3654	6
1593	32	8.5976	15206.5402	6
1593	33	8.8663	14624.0794	6
1593	34	9.135	14042.1742	6
1593	35	9.4036	13463.7041	6
1593	36	9.6723	12891.2328	6
1593	37	9.941	12327.0131	6
1593	38	10.2097	11772.9968	6
1593	39	10.4783	11230.8495	6
1593	40	10.747	10701.9679	6
1593	41	11.0157	10187.4996	6
1593	42	11.2844	9688.3631	6
1593	43	11.553	9205.2691	6
1593	44	11.8217	8738.7406	6
1593	45	12.0904	8289.1333	6
1593	46	12.3591	7856.6546	6
1593	47	12.6277	7441.3814	6
1593	48	12.8964	7043.2773	6
1593	49	13.1651	6662.208	6
1593	50	13.4338	6297.9555	6
1593	51	13.7024	5950.2314	6
1593	52	13.9711	5618.6883	6
1593	53	14.2398	5302.9305	6
1593	54	14.5085	5002.5237	6
1593	55	14.7772	4717.0031	6
1593	56	15.0458	4445.8808	6
1593	57	15.3145	4188.6524	6
1593	58	15.5832	3944.8026	6
1593	59	15.8519	3713.8102	6
1593	60	16.1205	3495.1523	6
1593	61	16.3892	3288.3077	6
1593	62	16.6579	3092.7604	6
1593	63	16.9266	2908.0017	6
1593	64	17.1952	2733.5326	6
1593	65	17.4639	2568.8655	6
1593	66	17.7326	2413.5257	6
1593	67	18.0013	2267.0521	6
1593	68	18.2699	2128.9986	6
1593	69	18.5386	1998.9344	6
1593	70	18.8073	1876.4442	6
1593	71	19.076	1761.129	6
1593	72	19.3446	1652.6058	6

1593	16	7.7037	17105.4691	6
1593	17	8.1852	16094.296	6
1593	18	8.6667	15056.9401	6
1593	19	9.1481	14013.669	6
1593	20	9.6296	12981.6703	6
1593	21	10.1111	11974.9086	6
1593	22	10.5926	11004.2421	6
1593	23	11.0741	10077.6968	6
1593	24	11.5556	9200.8192	6
1593	25	12.037	8377.0553	6
1593	26	12.5185	7608.1228	6
1593	27	13	6894.3548	6
1593	28	13.4815	6235.0065	6
1593	29	13.963	5628.5193	6
1593	30	14.4444	5072.7436	6
1593	31	14.9259	4565.1229	6
1593	32	15.4074	4102.8422	6
1593	33	15.8889	3682.9463	6
1593	34	16.3704	3302.4321	6
1593	35	16.8519	2958.3182	6
1593	36	17.3333	2647.6977	6
1593	37	17.8148	2367.7747	6
1593	38	18.2963	2115.8904	6
1593	39	18.7778	1889.5394	6
1593	40	19.2593	1686.3784	6
1593	41	19.7407	1504.2295	6
1593	42	20.2222	1341.0799	6
1593	43	20.7037	1195.0775	4
1593	44	21.1852	1064.5252	4
1593	45	21.6667	947.8732	4
1593	46	22.1481	843.7103	4
1593	47	22.6296	750.7554	4
1593	48	23.1111	667.8478	4
1593	49	23.5926	593.9382	4
1593	50	24.0741	528.0799	4
1593	51	24.5556	469.4201	4
1593	52	25.037	417.1915	4
1593	53	25.5185	370.7051	4
1593	54	26	329.3425	4
1593	55	26.4815	292.5494	4
1593	56	26.963	259.8297	4
1593	57	27.4444	230.7392	4
1593	58	27.9259	204.8812	4
1593	59	28.4074	181.9009	4
1593	60	28.8889	161.482	4
1593	61	29.3704	143.3419	4
1593	62	29.8519	127.2287	4
1593	63	30.3333	112.9181	4
1593	64	30.8148	100.21	4
1593	65	31.2963	88.9263	4
1593	66	31.7778	78.9084	4
1593	67	32.2593	70.0152	4
1593	68	32.7407	62.1211	4
1593	69	33.2222	55.1145	4
1593	70	33.7037	48.8961	4
1593	71	34.1852	43.3776	4
1593	72	34.6667	38.4806	4

1593	16	11.1588	9919.656	6
1593	17	11.8562	8680.0185	6
1593	18	12.5537	7554.161	6
1593	19	13.2511	6543.8003	6
1593	20	13.9485	5645.9645	6
1593	21	14.646	4854.6005	6
1593	22	15.3434	4161.8129	6
1593	23	16.0408	3558.7787	6
1593	24	16.7382	3036.3972	6
1593	25	17.4357	2585.731	6
1593	26	18.1331	2198.2894	6
1593	27	18.8305	1866.1962	6
6	28	19.5279	1582.2737	6
1593	29	20.2254	1340.0705	6
1593	30	20.9228	1133.8505	4
1593	31	21.6202	958.5579	4
1593	32	22.3176	809.7682	4
1593	33	23.0151	683.6319	4
1593	34	23.7125	576.8164	4
1593	35	24.4099	486.448	4
1593	36	25.1073	410.0578	4
1593	37	25.8048	345.5305	4
1593	38	26.5022	291.0586	4
1593	39	27.1996	245.1008	4
1593	40	27.897	206.3454	4
1593	41	28.5945	173.6777	4
1593	42	29.2919	146.1519	4
1593	43	29.9893	122.9665	4
1593	44	30.6868	103.4426	4
1593	45	31.3842	87.0065	4
1593	46	32.0816	73.1728	4
1593	47	32.779	61.5318	4
1593	48	33.4765	51.7378	4
1593	49	34.1739	43.499	4
1593	50	34.8713	36.5694	4
1593	51	35.5687	30.7416	4
1593	52	36.2662	25.8411	4
1593	53	36.9636	21.7206	4
1593	54	37.661	18.2563	4
1593	55	38.3584	15.3439	4
1593	56	39.0559	12.8957	4
1593	57	39.7533	10.8377	4
1593	58	40.4507	9.1079	4
1593	59	41.1481	7.654	4
1593	60	41.8456	6.4321	4
1593	61	42.543	5.4051	4
1593	62	43.2404	4.542	4
1593	63	43.9379	3.8167	4
1593	64	44.6353	3.2071	4
1593	65	45.3327	2.6949	4
1593	66	46.0301	2.2645	4
1593	67	46.7276	1.9028	4
1593	68	47.425	1.5988	4
1593	69	48.1224	1.3434	4
1593	70	48.8198	1.1288	4

Attachment C

1593	73	19.6133	1550.5076	6
1593	74	19.882	1454.4837	6
1593	75	20.1507	1364.1986	6
1593	76	20.4193	1279.3328	6
1593	77	20.688	1199.5816	4
1593	78	20.9567	1124.6552	4
1593	79	21.2254	1054.278	4
1593	80	21.494	988.1884	4
1593	81	21.7627	926.1381	4
1593	82	22.0314	867.8918	4
1593	83	22.3001	813.2264	4
1593	84	22.5687	761.9309	4
1593	85	22.8374	713.8058	4
1593	86	23.1061	668.6622	4
1593	87	23.3748	626.3218	4
1593	88	23.6434	586.6164	4
1593	89	23.9121	549.387	4
1593	90	24.1808	514.4837	4
1593	91	24.4495	481.7652	4
1593	92	24.7181	451.0984	4
1593	93	24.9868	422.3578	4
1593	94	25.2555	395.4252	4
1593	95	25.5242	370.1895	4
1593	96	25.7928	346.5459	4
1593	97	26.0615	324.3961	4
1593	98	26.3302	303.6475	4
1593	99	26.5989	284.2129	4
1593	100	26.8675	266.0107	4
1593	101	27.1362	248.9639	4
1593	102	27.4049	233.0004	4
1593	103	27.6736	218.0522	4
1593	104	27.9422	204.0557	4
1593	105	28.2109	190.9511	4
1593	106	28.4796	178.6823	4
1593	107	28.7483	167.1966	4
1593	108	29.0169	156.4446	4
1593	109	29.2856	146.3799	4
1593	110	29.5543	136.9591	4
1593	111	29.823	128.1413	4
1593	112	30.0917	119.8883	4
1593	113	30.3603	112.1642	4
1593	114	30.629	104.9354	4
1593	115	30.8977	98.1705	4
1593	116	31.1664	91.8398	4
1593	117	31.435	85.9158	4
1593	118	31.7037	80.3724	4
1593	119	31.9724	75.1853	4
1593	120	32.2411	70.3319	4
1593	121	32.5097	65.7907	4
1593	122	32.7784	61.5418	4
1593	123	33.0471	57.5665	4
1593	124	33.3158	53.8472	4
1593	125	33.5844	50.3676	4
1593	126	33.8531	47.1122	4
1593	127	34.1218	44.0668	4
1593	128	34.3905	41.2177	4
1593	129	34.6591	38.5524	4

1593	73	35.1481	34.1352	4
1593	74	35.6296	30.2797	4
1593	75	36.1111	26.8589	4
1593	76	36.5926	23.8239	4
1593	77	37.0741	21.1314	4
1593	78	37.5556	18.7427	4
1593	79	38.037	16.6238	4
1593	80	38.5185	14.7441	4
1593	81	39	13.0768	4
1593	82	39.4815	11.5978	4
1593	83	39.963	10.286	4
1593	84	40.4444	9.1224	4
1593	85	40.9259	8.0903	4
1593	86	41.4074	7.175	4
1593	87	41.8889	6.3631	4
1593	88	42.3704	5.6431	4
1593	89	42.8519	5.0044	4
1593	90	43.3333	4.4381	4
1593	91	43.8148	3.9358	4
1593	92	44.2963	3.4903	4
1593	93	44.7778	3.0952	4
1593	94	45.2593	2.7448	4
1593	95	45.7407	2.4341	4
1593	96	46.2222	2.1586	4
1593	97	46.7037	1.9142	4
1593	98	47.1852	1.6975	4
1593	99	47.6667	1.5053	4
1593	100	48.1481	1.3349	4

Attachment C

1593	130	34.9278	36.0591	4
1593	131	35.1965	33.7267	4
1593	132	35.4652	31.5449	4
1593	133	35.7338	29.5039	4
1593	134	36.0025	27.5948	4
1593	135	36.2712	25.809	4
1593	136	36.5399	24.1386	4
1593	137	36.8085	22.5761	4
1593	138	37.0772	21.1146	4
1593	139	37.3459	19.7476	4
1593	140	37.6146	18.469	4
1593	141	37.8832	17.273	4
1593	142	38.1519	16.1545	4
1593	143	38.4206	15.1082	4
1593	144	38.6893	14.1297	4
1593	145	38.9579	13.2144	4
1593	146	39.2266	12.3584	4
1593	147	39.4953	11.5578	4
1593	148	39.764	10.809	4
1593	149	40.0326	10.1087	4
1593	150	40.3013	9.4537	4
1593	151	40.57	8.8411	4
1593	152	40.8387	8.2682	4
1593	153	41.1073	7.7324	4
1593	154	41.376	7.2313	4
1593	155	41.6447	6.7626	4
1593	156	41.9134	6.3243	4
1593	157	42.182	5.9144	4
1593	158	42.4507	5.531	4
1593	159	42.7194	5.1725	4
1593	160	42.9881	4.8372	4
1593	161	43.2567	4.5236	4
1593	162	43.5254	4.2303	4
1593	163	43.7941	3.9561	4
1593	164	44.0628	3.6996	4
1593	165	44.3315	3.4598	4
1593	166	44.6001	3.2354	4
1593	167	44.8688	3.0257	4
1593	168	45.1375	2.8295	4
1593	169	45.4062	2.646	4
1593	170	45.6748	2.4744	4
1593	171	45.9435	2.314	4
1593	172	46.2122	2.1639	4
1593	173	46.4809	2.0236	4
1593	174	46.7495	1.8924	4
1593	175	47.0182	1.7697	4

Attachment D

```
1    *************************************************************************
     *
     *    ONE-DIMENSIONAL CONVECTIVE-DISPERSIVE EQUATION
     *
     *    FIRST-TYPE BOUNDARY CONDITION
     *    FINITE PROFILE
     *
     *    NO PRODUCTION OR DECAY
     *    LINEAR ADSORPTION (R)
     *    CONSTANT INITIAL CONCENTRATION (CI)
     *    INPUT CONCENTRATION = C0 (T.LE.T0)
     *                  = 0 (T.GT.T0)
     *
     *    TNT - Discharge Rate=77 gpm, Kd=5.0 ml/g                          *
     *
     *************************************************************************


     INPUT PARAMETERS
     ================

     V =   428.0000        D =  67838.0000
     R =    42.5000       T0 =      .0000
     CI = 2400.0000        C0 =      .0000
     XL = 1593.1900        TOL =   .000100

     CALCULATED EIGENVALUES
     ======================
      2.655507   5.456707   8.393501  11.410465  14.471429

     17.557554  20.658992  23.770310  26.888321  30.011057

     33.137243  36.266021  39.396792  42.529129  45.662717

     48.797318  51.932754  55.068884  58.205597  61.342804


DISTANCE    TIME    PORE VOLUME   CONCENTRATION    NUMBER
  (X)        (T)       (VVO)          (C)          OF TERM
  1593        1        0.2687         2400            0
  1593        2        0.5374         2400            0
  1593        3        0.806          2400            0
  1593        4        1.0747         2400            0
  1593        5        1.3434         2400            0
  1593        6        1.6121         2400            0
  1593        7        1.8807         2400            0
  1593        8        2.1494         2400            0
  1593        9        2.4181         2400            0
  1593       10        2.6868         2400            0
  1593       11        2.9554         2400            0
  1593       12        3.2241         2400            0
  1593       13        3.4928         2400            0
  1593       14        3.7615         2400            0
  1593       15        4.0301         2400            0
```

```
1    *************************************************************************
     *
     *    ONE-DIMENSIONAL CONVECTIVE-DISPERSIVE EQUATION
     *
     *    FIRST-TYPE BOUNDARY CONDITION
     *    FINITE PROFILE
     *
     *    NO PRODUCTION OR DECAY
     *    LINEAR ADSORPTION (R)
     *    CONSTANT INITIAL CONCENTRATION (CI)
     *    INPUT CONCENTRATION = C0 (T.LE.T0)
     *                  = 0 (T.GT.T0)
     *
     *    TNT - Discharge Rate=138 gpm, Kd=5.0 ml/g                         *
     *
     *************************************************************************


     INPUT PARAMETERS
     ================

     V =   767.0000        D = 121570.0000
     R =    42.5000       T0 =      .0000
     CI = 2400.0000        C0 =      .0000
     XL = 1593.1900        TOL =   .000100

     CALCULATED EIGENVALUES
     ======================
      2.655505   5.456705   8.393500  11.410464  14.471428

     17.557553  20.658992  23.770309  26.888320  30.011056

     33.137242  36.266020  39.396792  42.529129  45.662716

     48.797318  51.932754  55.068883  58.205596  61.342804


DISTANCE    TIME    PORE VOLUME   CONCENTRATION    NUMBER
  (X)        (T)       (VVO)          (C)          OF TERM
  1593        1        0.4815         2400            0
  1593        2        0.963          2400            0
  1593        3        1.4444         2400            0
  1593        4        1.9259         2400            0
  1593        5        2.4074         2400            0
  1593        6        2.8889         2400            0
  1593        7        3.3704         2400            0
  1593        8        3.8519         2400            0
  1593        9        4.3333         2400            0
  1593       10        4.8148         2400            0
  1593       11        5.2963       2399.9999          0
  1593       12        5.7778       2399.9994         12
  1593       13        6.2593       2399.9977         12
  1593       14        6.7407       2399.9917         10
  1593       15        7.2222       2399.9772         10
```

```
1    *************************************************************************
     *
     *    ONE-DIMENSIONAL CONVECTIVE-DISPERSIVE EQUATION
     *
     *    FIRST-TYPE BOUNDARY CONDITION
     *    FINITE PROFILE
     *
     *    NO PRODUCTION OR DECAY
     *    LINEAR ADSORPTION (R)
     *    CONSTANT INITIAL CONCENTRATION (CI)
     *    INPUT CONCENTRATION = C0 (T.LE.T0)
     *                  = 0 (T.GT.T0)
     *
     *    TNT - Discharge Rate=200 gpm, Kd=5.0 ml/g                         *
     *
     *************************************************************************


     INPUT PARAMETERS
     ================

     V =  1111.0000        D = 176093.0000
     R =    42.5000       T0 =      .0000
     CI = 2400.0000        C0 =      .0000
     XL = 1593.1900        TOL =   .000100

     CALCULATED EIGENVALUES
     ======================
      2.655508   5.456708   8.393503  11.410466  14.471430

     17.557554  20.658993  23.770310  26.888321  30.011057

     33.137243  36.266021  39.396793  42.529130  45.662717

     48.797319  51.932754  55.068884  58.205597  61.342805


DISTANCE    TIME    PORE VOLUME   CONCENTRATION    NUMBER
  (X)        (T)       (VVO)          (C)          OF TERM
  1593        1        0.6974         2400            0
  1593        2        1.3949         2400            0
  1593        3        2.0923         2400            0
  1593        4        2.7897         2400            0
  1593        5        3.4871         2400            0
  1593        6        4.1846         2400            0
  1593        7        4.882          2400            0
  1593        8        5.5794       2399.9997         12
  1593        9        6.2768       2399.9976         12
  1593       10        6.9743       2399.9864         10
  1593       11        7.6717       2399.9463         10
  1593       12        8.3691       2399.8301         10
  1593       13        9.0665       2399.5514         10
  1593       14        9.764        2398.9728         10
  1593       15       10.4614       2397.9015         10
```

Attachment D

1593	16	4.2988	2400	0	1593	16	7.7037	2399.9431	10	1593	16	11.1588	2396.0927	8
1593	17	4.5675	2400	0	1593	17	8.1852	2399.8722	10	1593	17	11.8562	2393.2605	8
1593	18	4.8362	2400	0	1593	18	8.6667	2399.7378	10	1593	18	12.5537	2389.0928	8
1593	19	5.1048	2400	0	1593	19	9.1481	2399.5024	10	1593	19	13.2511	2383.2698	8
1593	20	5.3735	2399.9998	12	1593	20	9.6296	2399.1158	10	1593	20	13.9485	2375.4824	8
1593	21	5.6422	2399.9996	12	1593	21	10.1111	2398.5152	10	1593	21	14.646	2365.4474	8
1593	22	5.9109	2399.9991	12	1593	22	10.5926	2397.6256	10	1593	22	15.3434	2352.921	8
1593	23	6.1795	2399.9981	12	1593	23	11.0741	2396.361	10	1593	23	16.0408	2337.7075	8
1593	24	6.4482	2399.9962	12	1593	24	11.5556	2394.6265	8	1593	24	16.7382	2319.6649	8
1593	25	6.7169	2399.9921	10	1593	25	12.037	2392.321	8	1593	25	17.4357	2298.7068	8
1593	26	6.9856	2399.9861	10	1593	26	12.5185	2389.3394	8	1593	26	18.1331	2274.8016	8
1593	27	7.2542	2399.9757	10	1593	27	13	2385.5764	8	1593	27	18.8305	2247.9691	8
1593	28	7.5229	2399.9592	10	1593	28	13.4815	2380.9287	8	1593	28	19.5279	2218.2762	8
1593	29	7.7916	2399.9336	10	1593	29	13.963	2375.2977	8	1593	29	20.2254	2185.831	8
1593	30	8.0603	2399.8954	10	1593	30	14.4444	2368.592	8	1593	30	20.9228	2150.7764	8
1593	31	8.3289	2399.8402	10	1593	31	14.9259	2360.7293	8	1593	31	21.6202	2113.2838	8
1593	32	8.5976	2399.7623	10	1593	32	15.4074	2351.6377	8	1593	32	22.3176	2073.5469	6
1593	33	8.8663	2399.6551	10	1593	33	15.8889	2341.257	8	1593	33	23.0151	2031.7752	6
1593	34	9.135	2399.5106	10	1593	34	16.3704	2329.5392	8	1593	34	23.7125	1988.1893	6
1593	35	9.4036	2399.3198	10	1593	35	16.8519	2316.4492	8	1593	35	24.4099	1943.0153	6
1593	36	9.6723	2399.0722	10	1593	36	17.3333	2301.9642	8	1593	36	25.1073	1896.4812	6
1593	37	9.941	2398.7563	10	1593	37	17.8148	2286.0742	8	1593	37	25.8048	1848.8126	6
1593	38	10.2097	2398.3593	10	1593	38	18.2963	2268.7806	8	1593	38	26.5022	1800.2302	6
1593	39	10.4783	2397.8673	10	1593	39	18.7778	2250.0966	8	1593	39	27.1996	1750.9472	6
1593	40	10.747	2397.2653	10	1593	40	19.2593	2230.0452	8	1593	40	27.897	1701.167	6
1593	41	11.0157	2396.5375	10	1593	41	19.7407	2208.6593	8	1593	41	28.5945	1651.0823	6
1593	42	11.2844	2395.6672	8	1593	42	20.2222	2185.9802	8	1593	42	29.2919	1600.8738	6
1593	43	11.553	2394.6371	8	1593	43	20.7037	2162.0564	8	1593	43	29.9893	1550.7092	6
1593	44	11.8217	2393.4294	8	1593	44	21.1852	2136.9433	8	1593	44	30.6868	1500.7435	6
1593	45	12.0904	2392.026	8	1593	45	21.6667	2110.7014	8	1593	45	31.3842	1451.118	6
1593	46	12.3591	2390.4084	8	1593	46	22.1481	2083.396	8	1593	46	32.0816	1401.9613	6
1593	47	12.6277	2388.5583	8	1593	47	22.6296	2055.0957	6	1593	47	32.779	1353.3888	6
1593	48	12.8964	2386.4574	8	1593	48	23.1111	2025.872	6	1593	48	33.4765	1305.5034	6
1593	49	13.1651	2384.0878	8	1593	49	23.5926	1995.7982	6	1593	49	34.1739	1258.396	6
1593	50	13.4338	2381.4318	8	1593	50	24.0741	1964.9489	6	1593	50	34.8713	1212.146	6
1593	51	13.7024	2378.4726	8	1593	51	24.5556	1933.3991	6	1593	51	35.5687	1166.8222	6
1593	52	13.9711	2375.1936	8	1593	52	25.037	1901.2236	6	1593	52	36.2662	1122.4828	6
1593	53	14.2398	2371.5794	8	1593	53	25.5185	1868.4969	6	1593	53	36.9636	1079.1768	6
1593	54	14.5085	2367.6152	8	1593	54	26	1835.2919	6	1593	54	37.661	1036.9443	6
1593	55	14.7772	2363.2875	8	1593	55	26.4815	1801.6805	6	1593	55	38.3584	995.8173	6
1593	56	15.0458	2358.5833	8	1593	56	26.963	1767.7324	6	1593	56	39.0559	955.8204	6
1593	57	15.3145	2353.4913	8	1593	57	27.4444	1733.5152	6	1593	57	39.7533	916.9711	6
1593	58	15.5832	2348.001	8	1593	58	27.9259	1699.0941	6	1593	58	40.4507	879.2812	6
1593	59	15.8519	2342.1032	8	1593	59	28.4074	1664.5319	6	1593	59	41.1481	842.7563	6
1593	60	16.1205	2335.7898	8	1593	60	28.8889	1629.8884	6	1593	60	41.8456	807.3976	6
1593	61	16.3892	2329.0541	8	1593	61	29.3704	1595.2207	6	1593	61	42.543	773.2015	6
1593	62	16.6579	2321.8905	8	1593	62	29.8519	1560.5828	6	1593	62	43.2404	740.1602	6
1593	63	16.9266	2314.2946	8	1593	63	30.3333	1526.026	6	1593	63	43.9379	708.2629	6
1593	64	17.1952	2306.2635	8	1593	64	30.8148	1491.5982	6	1593	64	44.6353	677.4953	6
1593	65	17.4639	2297.7951	8	1593	65	31.2963	1457.3446	6	1593	65	45.3327	647.8407	6
1593	66	17.7326	2288.8888	8	1593	66	31.7778	1423.3073	6	1593	66	46.0301	619.2797	6
1593	67	18.0013	2279.5449	8	1593	67	32.2593	1389.5255	6	1593	67	46.7276	591.7914	6
1593	68	18.2699	2269.765	8	1593	68	32.7407	1356.0354	6	1593	68	47.425	565.3529	6
1593	69	18.5386	2259.5516	8	1593	69	33.2222	1322.8705	6	1593	69	48.1224	539.9401	6
1593	70	18.8073	2248.9083	8	1593	70	33.7037	1290.0615	6	1593	70	48.8198	515.5277	6
1593	71	19.076	2237.8396	8	1593	71	34.1852	1257.6365	6	1593	71	49.5173	492.0896	6
1593	72	19.3446	2226.3509	8	1593	72	34.6667	1225.621	6	1593	72	50.2147	469.5988	6

Attachment D

1593	73	19.6133	2214.4487	8
1593	74	19.882	2202.14	8
1593	75	20.1507	2189.4326	8
1593	76	20.4193	2176.3352	8
1593	77	20.688	2162.857	8
1593	78	20.9567	2149.0077	8
1593	79	21.2254	2134.7977	8
1593	80	21.494	2120.2378	8
1593	81	21.7627	2105.3392	8
1593	82	22.0314	2090.1136	8
1593	83	22.3001	2074.5729	6
1593	84	22.5687	2058.7292	6
1593	85	22.8374	2042.5952	6
1593	86	23.1061	2026.1834	6
1593	87	23.3748	2009.5066	6
1593	88	23.6434	1992.5778	6
1593	89	23.9121	1975.4099	6
1593	90	24.1808	1958.0161	6
1593	91	24.4495	1940.4093	6
1593	92	24.7181	1922.6026	6
1593	93	24.9868	1904.6089	6
1593	94	25.2555	1886.4411	6
1593	95	25.5242	1868.1121	6
1593	96	25.7928	1849.6345	6
1593	97	26.0615	1831.0208	6
1593	98	26.3302	1812.2834	6
1593	99	26.5989	1793.4344	6
1593	100	26.8675	1774.4858	6
1593	101	27.1362	1755.4494	6
1593	102	27.4049	1736.3366	6
1593	103	27.6736	1717.1587	6
1593	104	27.9422	1697.9268	6
1593	105	28.2109	1678.6516	6
1593	106	28.4796	1659.3437	6
1593	107	28.7483	1640.0132	6
1593	108	29.0169	1620.6701	6
1593	109	29.2856	1601.3242	6
1593	110	29.5543	1581.9846	6
1593	111	29.823	1562.6606	6
1593	112	30.0917	1543.361	6
1593	113	30.3603	1524.0942	6
1593	114	30.629	1504.8685	6
1593	115	30.8977	1485.6917	6
1593	116	31.1664	1466.5716	6
1593	117	31.435	1447.5154	6
1593	118	31.7037	1428.5302	6
1593	119	31.9724	1409.6228	6
1593	120	32.2411	1390.7997	6
1593	121	32.5097	1372.0671	6
1593	122	32.7784	1353.4309	6
1593	123	33.0471	1334.8967	6
1593	124	33.3158	1316.4701	6
1593	125	33.5844	1298.1561	6
1593	126	33.8531	1279.9596	6
1593	127	34.1218	1261.8853	6
1593	128	34.3905	1243.9375	6
1593	129	34.6591	1226.1204	6

1593	73	35.1481	1194.038	6
1593	74	35.6296	1162.9081	6
1593	75	36.1111	1132.2499	6
1593	76	36.5926	1102.0796	6
1593	77	37.0741	1072.4115	6
1593	78	37.5556	1043.2578	6
1593	79	38.037	1014.6291	6
1593	80	38.5185	986.5342	6
1593	81	39	958.9802	6
1593	82	39.4815	931.9728	6
1593	83	39.963	905.5162	6
1593	84	40.4444	879.6134	6
1593	85	40.9259	854.2659	6
1593	86	41.4074	829.4745	6
1593	87	41.8889	805.2385	6
1593	88	42.3704	781.5565	6
1593	89	42.8519	758.4261	6
1593	90	43.3333	735.844	6
1593	91	43.8148	713.8064	6
1593	92	44.2963	692.3086	6
1593	93	44.7778	671.3454	6
1593	94	45.2593	650.9108	6
1593	95	45.7407	630.9985	6
1593	96	46.2222	611.6018	6
1593	97	46.7037	592.7134	6
1593	98	47.1852	574.3257	6
1593	99	47.6667	556.431	6
1593	100	48.1481	539.021	6
1593	101	48.6296	522.0874	6
1593	102	49.1111	505.6216	6
1593	103	49.5926	489.6147	6
1593	104	50.0741	474.0581	6
1593	105	50.5556	458.9425	6
1593	106	51.037	444.2591	6
1593	107	51.5185	429.9985	6
1593	108	52	416.1518	6
1593	109	52.4815	402.7096	6
1593	110	52.963	389.6629	6
1593	111	53.4444	377.0025	6
1593	112	53.9259	364.7193	6
1593	113	54.4074	352.8042	6
1593	114	54.8889	341.2482	6
1593	115	55.3704	330.0425	6
1593	116	55.8519	319.1782	6
1593	117	56.3333	308.6467	6
1593	118	56.8148	298.4392	6
1593	119	57.2963	288.5474	6
1593	120	57.7778	278.9629	6
1593	121	58.2593	269.6773	6
1593	122	58.7407	260.6827	6
1593	123	59.2222	251.971	6
1593	124	59.7037	243.5345	6
1593	125	60.1852	235.3654	6
1593	126	60.6667	227.4562	6
1593	127	61.1481	219.7996	6
1593	128	61.6296	212.3882	6
1593	129	62.1111	205.2151	6

1593	73	50.9121	448.028	6
1593	74	51.6095	427.3496	6
1593	75	52.307	407.5357	6
1593	76	53.0044	388.5585	6
1593	77	53.7018	370.3902	6
1593	78	54.3992	353.0031	6
1593	79	55.0967	336.3698	6
1593	80	55.7941	320.4635	6
1593	81	56.4915	305.2575	6
1593	82	57.189	290.7257	6
1593	83	57.8864	276.8424	6
1593	84	58.5838	263.5827	6
1593	85	59.2812	250.9222	6
1593	86	59.9787	238.8369	6
1593	87	60.6761	227.3038	6
1593	88	61.3735	216.3002	6
1593	89	62.0709	205.8044	6
1593	90	62.7684	195.7951	6
1593	91	63.4658	186.2518	6
1593	92	64.1632	177.1547	6
1593	93	64.8606	168.4847	6
1593	94	65.5581	160.2231	6
1593	95	66.2555	152.3523	6
1593	96	66.9529	144.8549	6
1593	97	67.6503	137.7145	4
1593	98	68.3478	130.9151	4
1593	99	69.0452	124.4414	4
1593	100	69.7426	118.2787	4
1593	101	70.4401	112.4128	4
1593	102	71.1375	106.8303	4
1593	103	71.8349	101.518	4
1593	104	72.5323	96.4635	4
1593	105	73.2298	91.6549	4
1593	106	73.9272	87.0807	4
1593	107	74.6246	82.73	4
1593	108	75.322	78.5922	4
1593	109	76.0195	74.6574	4
1593	110	76.7169	70.9159	4
1593	111	77.4143	67.3585	4
1593	112	78.1117	63.9765	4
1593	113	78.8092	60.7615	4
1593	114	79.5066	57.7055	4
1593	115	80.204	54.8009	4
1593	116	80.9014	52.0404	4
1593	117	81.5989	49.4169	4
1593	118	82.2963	46.924	4
1593	119	82.9937	44.5552	4
1593	120	83.6911	42.3044	4
1593	121	84.3886	40.1661	4
1593	122	85.086	38.1345	4
1593	123	85.7834	36.2046	4
1593	124	86.4809	34.3713	4
1593	125	87.1783	32.63	4
1593	126	87.8757	30.9759	4
1593	127	88.5731	29.405	4
1593	128	89.2706	27.9129	4
1593	129	89.968	26.496	4

Attachment D

1593	130	34.9278	1208.4379	6
1593	131	35.1965	1190.8937	6
1593	132	35.4652	1173.4913	6
1593	133	35.7338	1156.2339	6
1593	134	36.0025	1139.1246	6
1593	135	36.2712	1122.1661	6
1593	136	36.5399	1105.3611	6
1593	137	36.8085	1088.7121	6
1593	138	37.0772	1072.2212	6
1593	139	37.3459	1055.8907	6
1593	140	37.6146	1039.7222	6
1593	141	37.8832	1023.7177	6
1593	142	38.1519	1007.8785	6
1593	143	38.4206	992.2062	6
1593	144	38.6893	976.7019	6
1593	145	38.9579	961.3667	6
1593	146	39.2266	946.2016	6
1593	147	39.4953	931.2075	6
1593	148	39.764	916.3849	6
1593	149	40.0326	901.7344	6
1593	150	40.3013	887.2564	6
1593	151	40.57	872.9514	6
1593	152	40.8387	858.8193	6
1593	153	41.1073	844.8604	6
1593	154	41.376	831.0747	6
1593	155	41.6447	817.4619	6
1593	156	41.9134	804.0219	6
1593	157	42.182	790.7544	6
1593	158	42.4507	777.659	6
1593	159	42.7194	764.7352	6
1593	160	42.9881	751.9825	6
1593	161	43.2567	739.4002	6
1593	162	43.5254	726.9877	6
1593	163	43.7941	714.7442	6
1593	164	44.0628	702.6688	6
1593	165	44.3315	690.7607	6
1593	166	44.6001	679.019	6
1593	167	44.8688	667.4425	6
1593	168	45.1375	656.0303	6
1593	169	45.4062	644.7813	6
1593	170	45.6748	633.6943	6
1593	171	45.9435	622.7682	6
1593	172	46.2122	612.0017	6
1593	173	46.4809	601.3935	6
1593	174	46.7495	590.9423	6
1593	175	47.0182	580.6469	6
1593	176	47.2869	570.5058	6
1593	177	47.5556	560.5176	6
1593	178	47.8242	550.681	6
1593	179	48.0929	540.9945	6
1593	180	48.3616	531.4567	6
1593	181	48.6303	522.0659	6
1593	182	48.8989	512.8209	6
1593	183	49.1676	503.72	6
1593	184	49.4363	494.7617	6
1593	185	49.705	485.9445	6
1593	186	49.9736	477.2668	6

1593	130	62.5926	198.2733	6
1593	131	63.0741	191.556	6
1593	132	63.5556	185.0567	6
1593	133	64.037	178.7688	6
1593	134	64.5185	172.686	6
1593	135	65	166.8022	6
1593	136	65.4815	161.1114	6
1593	137	65.963	155.6076	6
1593	138	66.4444	150.2853	6
1593	139	66.9259	145.1388	6
1593	140	67.4074	140.1627	6
1593	141	67.8889	135.3517	4
1593	142	68.3704	130.7008	4
1593	143	68.8519	126.2048	4
1593	144	69.3333	121.8589	4
1593	145	69.8148	117.6584	4
1593	146	70.2963	113.5987	4
1593	147	70.7778	109.6754	4
1593	148	71.2593	105.884	4
1593	149	71.7407	102.2203	4
1593	150	72.2222	98.6804	4
1593	151	72.7037	95.26	4
1593	152	73.1852	91.9555	4
1593	153	73.6667	88.7631	4
1593	154	74.1481	85.679	4
1593	155	74.6296	82.6999	4
1593	156	75.1111	79.8222	4
1593	157	75.5926	77.0426	4
1593	158	76.0741	74.3579	4
1593	159	76.5556	71.7651	4
1593	160	77.037	69.2609	4
1593	161	77.5185	66.8426	4
1593	162	78	64.5073	4
1593	163	78.4815	62.2522	4
1593	164	78.963	60.0746	4
1593	165	79.4444	57.972	4
1593	166	79.9259	55.9418	4
1593	167	80.4074	53.9817	4
1593	168	80.8889	52.0892	4
1593	169	81.3704	50.2621	4
1593	170	81.8519	48.4983	4
1593	171	82.3333	46.7955	4
1593	172	82.8148	45.1517	4
1593	173	83.2963	43.5649	4
1593	174	83.7778	42.0332	4
1593	175	84.2593	40.5546	4
1593	176	84.7407	39.1275	4
1593	177	85.2222	37.7501	4
1593	178	85.7037	36.4205	4
1593	179	86.1852	35.1373	4
1593	180	86.6667	33.8989	4
1593	181	87.1481	32.7036	4
1593	182	87.6296	31.5501	4
1593	183	88.1111	30.4369	4
1593	184	88.5926	29.3625	4
1593	185	89.0741	28.3258	4
1593	186	89.5556	27.3253	4

1593	130	90.6654	25.1503	4
1593	131	91.3628	23.8725	4
1593	132	92.0603	22.6591	4
1593	133	92.7577	21.5069	4
1593	134	93.4551	20.4128	4
1593	135	94.1525	19.3741	4
1593	136	94.85	18.3878	4
1593	137	95.5474	17.4514	4
1593	138	96.2448	16.5625	4
1593	139	96.9422	15.7185	4
1593	140	97.6397	14.9173	4
1593	141	98.3371	14.1567	4
1593	142	99.0345	13.4347	4
1593	143	99.732	12.7494	4
1593	144	100.4294	12.0988	4
1593	145	101.1268	11.4813	4
1593	146	101.8242	10.8951	4
1593	147	102.5217	10.3388	4
1593	148	103.2191	9.8107	4
1593	149	103.9165	9.3095	4
1593	150	104.6139	8.8338	4
1593	151	105.3114	8.3823	4
1593	152	106.0088	7.9538	4
1593	153	106.7062	7.5472	4
1593	154	107.4036	7.1612	4
1593	155	108.1011	6.795	4
1593	156	108.7985	6.4474	4
1593	157	109.4959	6.1175	4
1593	158	110.1933	5.8045	4
1593	159	110.8908	5.5074	4
1593	160	111.5882	5.2255	4
1593	161	112.2856	4.958	4
1593	162	112.9831	4.7042	4
1593	163	113.6805	4.4633	4
1593	164	114.3779	4.2347	4
1593	165	115.0753	4.0178	4
1593	166	115.7728	3.812	4
1593	167	116.4702	3.6168	4
1593	168	117.1676	3.4315	4
1593	169	117.865	3.2556	4
1593	170	118.5625	3.0888	4
1593	171	119.2599	2.9305	4
1593	172	119.9573	2.7803	4
1593	173	120.6547	2.6378	4
1593	174	121.3522	2.5026	4
1593	175	122.0496	2.3743	4

1593	187	50.2423	468.727	6
1593	188	50.511	460.3236	6
1593	189	50.7797	452.0551	6
1593	190	51.0483	443.9197	6
1593	191	51.317	435.916	6
1593	192	51.5857	428.0423	6
1593	193	51.8544	420.2971	6
1593	194	52.123	412.6787	6
1593	195	52.3917	405.1856	6
1593	196	52.6604	397.8162	6
1593	197	52.9291	390.5688	6
1593	198	53.1977	383.4419	6
1593	199	53.4664	376.4339	6
1593	200	53.7351	369.5432	6
1593	201	54.0038	362.7682	6
1593	202	54.2724	356.1075	6
1593	203	54.5411	349.5593	6
1593	204	54.8098	343.1223	6
1593	205	55.0785	336.7947	6
1593	206	55.3471	330.5751	6
1593	207	55.6158	324.4619	6
1593	208	55.8845	318.4537	6
1593	209	56.1532	312.5489	6
1593	210	56.4218	306.746	6
1593	211	56.6905	301.0436	6
1593	212	56.9592	295.4401	6
1593	213	57.2279	289.9341	6
1593	214	57.4965	284.5242	6
1593	215	57.7652	279.2088	6
1593	216	58.0339	273.9866	6
1593	217	58.3026	268.8562	6
1593	218	58.5712	263.8162	6
1593	219	58.8399	258.8651	6
1593	220	59.1086	254.0016	6
1593	221	59.3773	249.2243	6
1593	222	59.646	244.532	6
1593	223	59.9146	239.9232	6
1593	224	60.1833	235.3967	6
1593	225	60.452	230.951	6
1593	226	60.7207	226.5851	6
1593	227	60.9893	222.2975	6
1593	228	61.258	218.087	6
1593	229	61.5267	213.9525	6
1593	230	61.7954	209.8925	6
1593	231	62.064	205.906	6
1593	232	62.3327	201.9917	6
1593	233	62.6014	198.1485	6
1593	234	62.8701	194.3751	6
1593	235	63.1387	190.6705	6
1593	236	63.4074	187.0334	6
1593	237	63.6761	183.4628	6
1593	238	63.9448	179.9576	6
1593	239	64.2134	176.5165	6
1593	240	64.4821	173.1387	6
1593	241	64.7508	169.8229	6
1593	242	65.0195	166.5682	6
1593	243	65.2881	163.3735	6

1593	187	90.037	26.3599	4
1593	188	90.5185	25.4282	4
1593	189	91	24.5293	4
1593	190	91.4815	23.6618	4
1593	191	91.963	22.8248	4
1593	192	92.4444	22.0172	4
1593	193	92.9259	21.238	4
1593	194	93.4074	20.4861	4
1593	195	93.8889	19.7606	4
1593	196	94.3704	19.0607	4
1593	197	94.8519	18.3854	4
1593	198	95.3333	17.7339	4
1593	199	95.8148	17.1053	4
1593	200	96.2963	16.4989	4
1593	201	96.7778	15.9138	4
1593	202	97.2593	15.3494	4
1593	203	97.7407	14.8048	4
1593	204	98.2222	14.2795	4
1593	205	98.7037	13.7727	4
1593	206	99.1852	13.2838	4
1593	207	99.6667	12.8122	4
1593	208	100.1481	12.3572	4
1593	209	100.6296	11.9183	4
1593	210	101.1111	11.495	4
1593	211	101.5926	11.0866	4
1593	212	102.0741	10.6926	4
1593	213	102.5556	10.3126	4
1593	214	103.037	9.946	4
1593	215	103.5185	9.5924	4
1593	216	104	9.2514	4
1593	217	104.4815	8.9224	4
1593	218	104.963	8.605	4
1593	219	105.4444	8.2989	4
1593	220	105.9259	8.0037	4
1593	221	106.4074	7.7189	4
1593	222	106.8889	7.4442	4
1593	223	107.3704	7.1793	4
1593	224	107.8519	6.9238	4
1593	225	108.3333	6.6773	4
1593	226	108.8148	6.4396	4
1593	227	109.2963	6.2103	4
1593	228	109.7778	5.9891	4
1593	229	110.2593	5.7758	4
1593	230	110.7407	5.5701	4
1593	231	111.2222	5.3717	4
1593	232	111.7037	5.1803	4
1593	233	112.1852	4.9958	4
1593	234	112.6667	4.8178	4
1593	235	113.1481	4.6461	4
1593	236	113.6296	4.4805	4
1593	237	114.1111	4.3208	4
1593	238	114.5926	4.1668	4
1593	239	115.0741	4.0183	4
1593	240	115.5556	3.875	4
1593	241	116.037	3.7369	4
1593	242	116.5185	3.6037	4
1593	243	117	3.4752	4

Attachment D

1593	244	65.5568	160.2378	6
1593	245	65.8255	157.1601	6
1593	246	66.0942	154.1394	6
1593	247	66.3628	151.1746	6
1593	248	66.6315	148.2649	6
1593	249	66.9002	145.4093	6
1593	250	67.1689	142.6068	6
1593	251	67.4375	139.8566	6
1593	252	67.7062	137.1577	4
1593	253	67.9749	134.5091	4
1593	254	68.2436	131.9102	4
1593	255	68.5122	129.3599	4
1593	256	68.7809	126.8573	4
1593	257	69.0496	124.4018	4
1593	258	69.3183	121.9924	4
1593	259	69.5869	119.6283	4
1593	260	69.8556	117.3087	4
1593	261	70.1243	115.0329	4
1593	262	70.393	112.7999	4
1593	263	70.6616	110.6092	4
1593	264	70.9303	108.4598	4
1593	265	71.199	106.3512	4
1593	266	71.4677	104.2825	4
1593	267	71.7363	102.253	4
1593	268	72.005	100.262	4
1593	269	72.2737	98.3088	4
1593	270	72.5424	96.3927	4
1593	271	72.811	94.5132	4
1593	272	73.0797	92.6694	4
1593	273	73.3484	90.8607	4
1593	274	73.6171	89.0866	4
1593	275	73.8858	87.3463	4
1593	276	74.1544	85.6393	4
1593	277	74.4231	83.9649	4
1593	278	74.6918	82.3226	4
1593	279	74.9605	80.7117	4
1593	280	75.2291	79.1317	4
1593	281	75.4978	77.582	4
1593	282	75.7665	76.062	4
1593	283	76.0352	74.5713	4
1593	284	76.3038	73.1092	4
1593	285	76.5725	71.6752	4
1593	286	76.8412	70.2688	4
1593	287	77.1099	68.8895	4
1593	288	77.3785	67.5368	4
1593	289	77.6472	66.2102	4
1593	290	77.9159	64.9092	4
1593	291	78.1846	63.6333	4
1593	292	78.4532	62.3821	4
1593	293	78.7219	61.155	4
1593	294	78.9906	59.9517	4
1593	295	79.2593	58.7717	4
1593	296	79.5279	57.6146	4
1593	297	79.7966	56.4799	4
1593	298	80.0653	55.3672	4
1593	299	80.334	54.276	4
1593	300	80.6026	53.2061	4

1593	244	117.4815	3.3512	4
1593	245	117.963	3.2317	4
1593	246	118.4444	3.1165	4
1593	247	118.9259	3.0053	4
1593	248	119.4074	2.8981	4
1593	249	119.8889	2.7947	4
1593	250	120.3704	2.696	4

Attachment D

1593	301	80.8713	52.1569	4
1593	302	81.14	51.1281	4
1593	303	81.4087	50.1194	4
1593	304	81.6773	49.1302	4
1593	305	81.946	48.1603	4
1593	306	82.2147	47.2093	4
1593	307	82.4834	46.2768	4
1593	308	82.752	45.3625	4
1593	309	83.0207	44.466	4
1593	310	83.2894	43.587	4
1593	311	83.5581	42.7252	4
1593	312	83.8267	41.8802	4
1593	313	84.0954	41.0517	4
1593	314	84.3641	40.2394	4
1593	315	84.6328	39.443	4
1593	316	84.9014	38.6622	4
1593	317	85.1701	37.8966	4
1593	318	85.4388	37.146	4
1593	319	85.7075	36.4102	4
1593	320	85.9761	35.6887	4
1593	321	86.2448	34.9814	4
1593	322	86.5135	34.2879	4
1593	323	86.7822	33.6081	4
1593	324	87.0508	32.9416	4
1593	325	87.3195	32.2882	4
1593	326	87.5882	31.6476	4
1593	327	87.8569	31.0196	4
1593	328	88.1255	30.4039	4
1593	329	88.3942	29.8004	4
1593	330	88.6629	29.2087	4
1593	331	88.9316	28.6286	4
1593	332	89.2003	28.06	4
1593	333	89.4689	27.5025	4
1593	334	89.7376	26.9561	4
1593	335	90.0063	26.4204	4
1593	336	90.275	25.8952	4
1593	337	90.5436	25.3804	4
1593	338	90.8123	24.8758	4
1593	339	91.081	24.3811	4
1593	340	91.3497	23.8961	4
1593	341	91.6183	23.4208	4
1593	342	91.887	22.9548	4
1593	343	92.1557	22.498	4
1593	344	92.4244	22.0502	4
1593	345	92.693	21.6113	4
1593	346	92.9617	21.181	4
1593	347	93.2304	20.7593	4
1593	348	93.4991	20.3459	4
1593	349	93.7677	19.9406	4
1593	350	94.0364	19.5434	4
1593	351	94.3051	19.154	4
1593	352	94.5738	18.7724	4
1593	353	94.8424	18.3983	4
1593	354	95.1111	18.0316	4
1593	355	95.3798	17.6721	4
1593	356	95.6485	17.3198	4
1593	357	95.9171	16.9745	4

1593	358	96.1858	16.636	4
1593	359	96.4545	16.3042	4
1593	360	96.7232	15.979	4
1593	361	96.9918	15.6602	4
1593	362	97.2605	15.3478	4
1593	363	97.5292	15.0416	4
1593	364	97.7979	14.7414	4
1593	365	98.0665	14.4472	4
1593	366	98.3352	14.1588	4
1593	367	98.6039	13.8762	4
1593	368	98.8726	13.5991	4
1593	369	99.1412	13.3276	4
1593	370	99.4099	13.0615	4
1593	371	99.6786	12.8006	4
1593	372	99.9473	12.545	4
1593	373	100.2159	12.2944	4
1593	374	100.4846	12.0488	4
1593	375	100.7533	11.808	4
1593	376	101.022	11.5721	4
1593	377	101.2906	11.3409	4
1593	378	101.5593	11.1142	4
1593	379	101.828	10.8921	4
1593	380	102.0967	10.6744	4
1593	381	102.3653	10.461	4
1593	382	102.634	10.2519	4
1593	383	102.9027	10.0469	4
1593	384	103.1714	9.846	4
1593	385	103.4401	9.6491	4
1593	386	103.7087	9.4561	4
1593	387	103.9774	9.267	4
1593	388	104.2461	9.0817	4
1593	389	104.5148	8.9	4
1593	390	104.7834	8.7219	4
1593	391	105.0521	8.5475	4
1593	392	105.3208	8.3764	4
1593	393	105.5895	8.2088	4
1593	394	105.8581	8.0446	4
1593	395	106.1268	7.8836	4
1593	396	106.3955	7.7258	4
1593	397	106.6642	7.5711	4
1593	398	106.9328	7.4196	4
1593	399	107.2015	7.2711	4
1593	400	107.4702	7.1255	4
1593	401	107.7389	6.9828	4
1593	402	108.0075	6.843	4
1593	403	108.2762	6.706	4
1593	404	108.5449	6.5717	4
1593	405	108.8136	6.4401	4
1593	406	109.0822	6.3111	4
1593	407	109.3509	6.1847	4
1593	408	109.6196	6.0609	4
1593	409	109.8883	5.9394	4
1593	410	110.1569	5.8205	4
1593	411	110.4256	5.7039	4
1593	412	110.6943	5.5896	4
1593	413	110.963	5.4776	4
1593	414	111.2316	5.3678	4

Attachment D

1593	415	111.5003	5.2603	4
1593	416	111.769	5.1549	4
1593	417	112.0377	5.0516	4
1593	418	112.3063	4.9503	4
1593	419	112.575	4.8511	4
1593	420	112.8437	4.7539	4
1593	421	113.1124	4.6586	4
1593	422	113.381	4.5652	4
1593	423	113.6497	4.4737	4
1593	424	113.9184	4.384	4
1593	425	114.1871	4.2961	4
1593	426	114.4557	4.21	4
1593	427	114.7244	4.1256	4
1593	428	114.9931	4.0429	4
1593	429	115.2618	3.9618	4
1593	430	115.5304	3.8824	4
1593	431	115.7991	3.8045	4
1593	432	116.0678	3.7282	4
1593	433	116.3365	3.6534	4
1593	434	116.6051	3.5802	4
1593	435	116.8738	3.5084	4
1593	436	117.1425	3.438	4
1593	437	117.4112	3.369	4
1593	438	117.6798	3.3014	4
1593	439	117.9485	3.2352	4
1593	440	118.2172	3.1703	4
1593	441	118.4859	3.1067	4
1593	442	118.7546	3.0444	4
1593	443	119.0232	2.9833	4
1593	444	119.2919	2.9234	4
1593	445	119.5606	2.8648	4
1593	446	119.8293	2.8073	4
1593	447	120.0979	2.751	4
1593	448	120.3666	2.6958	4
1593	449	120.6353	2.6417	4
1593	450	120.904	2.5887	4

Appendix C: Operating and Maintenance Calculations

Alternative 1 - No Action | Nov 22, 1993

Only operating cost is for this alternative is the cost for the 5-yr Review.

The 5yr Review was assumed to take 250 hr every 5yrs. In order to facilitate the calculation of annual costs, the 250 hours was divided over the 5years + 50hr/yr was Assumed

The Labor Rate for this review is based upon a mid level engineer, geologist or chemist

Labor Rate = $23/hr x 3.5 markup = $80/hr

Cost of 5-yr Review = $80/hr x 50 hr/yr = $4,000/yr

Alternative 2 - Institutional Controls | Nov 22, 1993

Monitoring - Quarterly Sampling of ground water for explosives and inorganics at 19 wells.

Sample Collection

Unconfined Aquifer - 15 wells
Basalt Interbeds - 4 wells

Time to complete one sampling event is ~ 10 days

Sampling events take place 4 times / yr

10 days x 4 sampling events/yr = 40 day/yr

Two samplers / event = 80 persondays/yr x 8 hr/person day

= 640 hr / yr

Labor Rate = $8.50 / hr x 3.5 markup = $30 / hr

Supervision of sample collection -

1 day / sampling event x 4 sampling events/yr = 4 day/yr x 8 hr/day

= 32 hr/yr

Labor Rate = $14.30 / hr x 3.5 markup = $50 / hr

Sample Analysis

19 sampling locations / event x 2 samples / location = 38 samples/event

38 samples / event x 4 events / yr = 152 samples / yr

Avg sample cost is ≈ $150 / sample

Data Review + Reporting -

1 day / event x 4 events/yr x 8 $\frac{\text{person hr}}{\text{day}}$ = 32 person hr / yr

National Brand

Alternative 3A assumes the use of UV/oxidation w/ GAC polishing for 30yrs to remediate the aquifer to PRGs. The flow rate for this alternative is 135gpm. The following categories of operating costs are developed below:

- Monitoring
- 5-yr Review
- Metals Precipitation
- Electrical
- Ozone
- GAC
- GAC Incineration
- Disposal

Monitoring - See Costing in Alt. 2

5-yr Review - see Costing in Alt 1

Metal Precipitation - operating cost based on conversations

With Andco Environmental Processes and verified based on EPA study for the removal of heavy metals.

Cost for chemicals to treat UMDA ground water was $0.4 /1000gal

Electrical - Useage was developed based on UV lights, pumps, + misc. electrical for heating building, lighting, ect.

Electrical cost estimate for the UV lights was based on conversations between Kevin Cahill of ADL + Doug Reed of Solar Chem. The Solar Chem electrical estimate was used because it was higher than Ultrox's estimate and was therefore belived to be more conservative.

75 kWh /1000gal of water treated

$$135 \frac{gal}{min} \times 60 \frac{min}{hr} \times 24 \frac{hr}{day} \times 365 \frac{day}{yr} = 70,956,000 \text{ gal/yr}$$

Alternative 3A (cont) Nov 22, 1993

Electrical (cont.)

$70,956,000 \text{ gal/yr} \times 75 \text{ kWhr}/1000 \text{ gal} = 5.3 \text{ M kWhr/yr}$

an additional 15% of kWhr was added for the pumps and misc. electrical usage.

$5.3 \text{ M kWhr/yr} \times 1.15$ (for pumps + misc electrical) $= 6.1 \text{ M kWhr}$

Ozone - Costs are based on electrical costs of \$0.06/kWh and an O_3 dose of 2 mg/l/min. Based on these inputs the Milan report stated an O_3 electrical cost of \$0.25/1000 gal

GAC usage - GAC was used w/ UV/ox to polish the ground water stream. Total explosive concentration on GAC was limited to 7% inorder to avoid having a reactive material.

Explosive loading to GAC assuming a loading of 10% of the original concentration of 5,400 μg/L

$540 \text{ μg/L} \times 3.79 \text{ L/gal} \times 135 \text{ gal/min} \times 525{,}600 \frac{\text{min}}{\text{yr}} \times 1\text{g}/1\times10^6 \text{μg}$

$\times 1\text{lb}/454\text{g} = 320 \text{ lb/yr}$

$320 \text{ lb Explosive/yr} \times \text{lb GAC}/0.07 \text{ lb Explosive} = 4570 \text{ lb GAC/yr}$

$4{,}570 \text{ lb GAC/yr} \times 1 \text{ ton}/2000 \text{ lb} = 2.3 \text{ tons GAC/yr}$

Carbon Change out

$365 \text{ days/yr} \times 1 \text{ yr}/2.3 \text{ tons GAC} = 159 \text{ days/ton}$

National® Brand

Alternative 3A (cont.) Nov 22, 1993

GAC Incineration - Spent GAC was calculated in previous calc. quanity of GAC / drum is assumed to be 335 lb/drum

$$2.3\ \text{tons/yr} \times 2000\ \text{lb/ton} \times 1\ \text{drum}/335\ \text{lbs} = 13.7\ \text{drums}$$

Disposal - This is for the disposal of hydroxide sludges from the metal precipitation unit and a small amount of suspended solids from the extration wells. Solids production is based on conversations with Andco Environmental Processes. (5.2 lb/1000 gal)

$$5.2\ \text{lb}/1000\ \text{gal} \times 135\ \text{gal/min} \times 525{,}600\ \frac{\text{min}}{\text{yr}} \times 1\ \text{ton}/2000\ \text{lb}$$

$$= 185\ \text{tons/yr}$$

Alternative 3B – UV/OX to PRGs in 10 yrs. DEC 7, 1993

Alternative 3B assumes the use of UV/oxidation w/ GAC polishing for 10 yrs to remediate the aquifer to PRGs. The flow rate for this alternative is 333 gpm. The following categories of operating costs are developed below:

- Monitoring
- 5-yr Review
- Metals Precipitation
- Electrical
- Ozone
- GAC
- GAC Incineration
- Disposal

Monitoring – See Costing in Alt. 2

5-yr Review – see Costing in Alt 1

Metal Precipitation – operating cost based on conversations

With Andco Environmental Processes and verified based on EPA study for the removal of heavy metals.

Cost for chemicals to treat UMDA ground water was $0.4 /1000 gal

Electrical – Useage was developed based on UV lights, pumps, + misc. electrical for heating building, lighting, ect.

Electrical cost estimate for the UV lights was based on conversations between Kevin Cahill of ADL + Doug Reed of Solar Chem. The Solar Chem electrical estimate was used because it was higher than Ultrox's estimate and was therefore belived to be more conservative.

75 KWh /1000 gal of water treated

$$333\,\frac{gal}{min} \times 60\,\frac{min}{hr} \times \frac{24\,hr}{day} \times \frac{365\,day}{yr} = 175{,}448{,}000\ gal/yr$$

42-392 100 RECYCLED WHITE 5 SQUARE
42-399 200 RECYCLED WHITE 5 SQUARE
Made in U.S.A.

Electrical (cont.)

173,448,000 gal/yr × 75 kWhr/1000 gal = 13.0 M kWhr/yr

an additional 15% of kWhr was added for the pumps and misc. electrical usage.

13.0 M kWhr/yr × 1.15 (for pumps + misc electrical) = 15.0 M kWhr

Ozone - Costs are based on electrical costs of $0.06/kWh and an O_3 dose of 2 mg/l/min. Based on these inputs the Milan report stated an O_3 electrical cost of $0.25/1000 gal

GAC usage - GAC was used w/ UV/ox to polish the ground water stream. Total explosive concentration on GAC was limited to 7% in order to avoid having a reactive material.

Explosive loading to GAC assuming a loading of 10% of the original concentration of 5,400 μg/L

$540 \, \mu g/L \times 3.79 \, L/gal \times 333 \, gal/min \times 525{,}600 \, \frac{min}{yr} \times 1g/1\times10^{+6} \mu g$

$\times 1 lb/454 g = 789 \, lb/yr$

$789 \, lb \, explosive/yr \times lb \, GAC/0.07 \, lb \, Explosive = 11{,}270 \, lb \, GAC/yr$

$11{,}270 \, lb \, GAC/yr \times 1 \, ton/2000 \, lb = 5.6 \, tons \, GAC/yr$

Carbon Change out

$365 \, days/yr \times 1 \, yr/5.6 \, tons \, GAC = 65 \, days/ton$

Alternative 3B (cont.) Dec. 7, 1993

GAC Incineration - Spent GAC was calculated in previous calc. quanity of GAC / drum is assumed to be 335 lb/drum

5.6 tons/yr × 2000 lb/ton × 1 drum/335 lbs = 33.4 drums

Disposal - This is for the disposal of hydroxide sludges from the metal precipitation unit and a small amount of suspended solids from the extration wells. Solids production is based on conversations with Andco Environmental Processes. (5.2 lb/1000 gal)

5.2 lb/1000 gal × 333 gal/min × 525,600 $\frac{\text{min}}{\text{yr}}$ × 1 ton/2000 lb

= 455 tons/yr

Alternative 4A — GAC to PRGs in 30 yr Nov 22, 1993

Alternative 4A assumes the use of GAC for 30 yrs to remediate the aquifer to PRGs. The flow Rate for this Alternative is 135 gpm. The following categories of operating costs are developed below:

- Monitoring
- 5-yr review
- Electrical
- GAC Usage
- GAC Incineration

Monitoring - see costing in Alt. 2

5-yr Review - See costing in Alt 1

Electrical - Electrical usage was developed based on pumps, lighting, and other misc. electrical.

Pumps -

Extraction pumps maximum rating 100 gpm, 3 hp, motor efficiency of 60%

3hp/0.6 × 3 pumps × 24hr/day × 365day/yr × 0.765 kw/hp

= 100,500 kw/yr

Feed pump maximum rating 200 gpm, 5 hp, motor efficiency of 75%

5hp/0.75 × 1 pump × 24hr/day × 365day/yr × 0.765 kw/hp

= 44,700 kw/yr

Discharge pump maximum rating 200 gpm, 7 hp, motor efficiency of 75%

7hp/0.75 × 1 pump × 24 hr/day × 365 day/yr × 0.765 $\frac{kw}{hp}$

= 62,500 kw/yr

Electrical (cont.)

Total pump electrical usage

= 100,500 kw/yr + 44,700 kw/yr + 62,500 kw/yr

= 207,700 kw/yr

Lighting - assume a 10,000 ft^2 building with lighting requirements of 30 ft-candles and a maintenance factor of 0.70.

$$= \frac{10,000\ ft^2 \times 30\ ft\text{-candles}}{50\ lumens/wat\ (0.70)} = 8,600\ watts$$

8.6 kw × 24 hr/day × 365 days/yr = 75,000 kw/yr

Misc. Electrical - An additional 50% electrical was assumed for other needs offices, outside lighting, ect

= (207,700 kw/yr + 75,000 kw/yr) × 0.5

= 141,000 kw/yr

Total electrical is 424,000 kw/yr

GAC Usage - GAC was used to remove all the explosive contamination. Total explosive concentration on GAC was limited to 7% in order to avoid having an explosive material.

Explosive loading to the GAC was assumed to be 5400 µg/L

5,400 µg/L × 3.79 L/gal × 135 gal/min × 525,600 min/yr × 1g/1×10^{+6} µg × lb/454g = 3205 lb Explosive/yr

3205 lb explosive/yr × lb GAC/0.07 lb explosive = 45,800 lb GAC/yr

$$45,800\ lb\ GAC/yr \times \frac{1\ ton}{2000\ lb} = 22.8\ tons$$

Alternative 4A (cont) Nov 22, 1993

GAC usage (cont)

Carbon changeout

365 days/yr × 1 yr / 22.8 tons GAC = 16 days/ton GAC

GAC Incineration - Spent GAC was calculated in previous calc. quantity of GAC/drum is assumed to be 335 lb/drum

22.8 tons GAC × 2000 lb/ton × 1 drum/335 lb = 137 drums

Alternative 4B – GAC to PRGs in 10 yr

Dec 7, 1998

Alternative 4B assumes the use of GAC for 10 yrs to remediate the aquifer to PRGs. The flow Rate for this Alternative is 333 gpm. The following categories of operating costs are developed below:

- Monitoring
- 5-yr review
- Electrical
- GAC usage
- GAC Incineration

Monitoring – see costing in Alt. 2

5-yr Review – See costing in Alt 1

Electrical – Electrical usage was developed based on pumps, lighting, and other misc. electrical.

Pumps –

Extraction pumps maximum rating 250 gpm, 7.5 hp, motor efficiency of 75%

$7.5\,hp/0.75 \times 3\text{ pumps} \times 24\,hr/day \times 365\,day/yr \times 0.765\,kw/hp$

$= 201{,}050\ kw/yr$

Feed pump maximum rating 350 gpm, 7 hp, efficiency of 75%

$7\,hp/0.75 \times 1\text{ pump} \times 24\,hr/day \times 365\,day/yr \times 0.765\,kw/hp$

$= 62{,}550\ kw/yr$

Discharge pump maximum rating 350 gpm, 8 hp motor efficiency of 75%

$8\,hp/0.75 \times 1\text{ pump} \times 24\,hr/day \times 365\,day/yr \times 0.765\,\frac{kw}{hp}$

$= 71{,}480\ kw/yr$

Alternative 4B (cont) DEC 7, 1993

Electrical (cont.)

Total pump electrical usage

= 201,050 kw/yr + 62,550 kw/yr + 71,480 kw/yr

= 335,080 kw/yr

Lighting - assume a 10,000 ft^2 building with lighting requirements of 30 ft-candles and a maintenance factor of 0.70.

$$= \frac{10{,}000\ \text{ft}^2 \times 30\ \text{ft-candles}}{50\ \text{lumens/wat}\ (0.70)} = 8{,}600\ \text{watts}$$

8.6 kw × 24 hr/day × 365 days/yr = 75,000 kw/yr

Misc. Electrical - An additional 50% electrical was assumed for other needs offices, outside lighting, ect

= (335,080 kw/yr + 75,000 kw/yr) × 0.5

= 205,040 kw/yr

Total electrical is 615,120 kw/yr

GAC Usage - GAC was used to remove all the explosive contamination. Total explosive concentration on GAC was limited to 7% in order to avoid having an explosive material.

Explosive loading to the GAC was assumed to be 5400 μg/L

$$5{,}400\ \mu g/L \times 3.79\ L/gal \times 333\ gal/min \times 525{,}600\ min/yr \times {}^{1g}/_{1\times10^{-6}\mu g}$$

$$\times\ {}^{lb}/_{454g} = 7905\ \text{lb Explosive/yr}$$

$$7905\ \text{lb explosive/yr} \times {}^{\text{lb GAC}}/_{0.07\ \text{lb explosive}} = 112{,}930\ \text{lb GAC/yr}$$

$$112{,}930\ \text{lb GAC/yr} \times \frac{1\ \text{ton}}{2000\ \text{lb}} = 56.5\ \text{tons}$$

Alternative 4B (cont) DEC 7, 1993

GAC usage (cont)

Carbon changeout

365 days/yr × 1 yr/56.5 tons GAC = 6.5 days/ton GAC

GAC Incineration - Spent GAC was calculated in previous calc. quantity of GAC/drum is assumed to be 335 lb/drum

56.5 tons GAC × 2000 lb/ton × 1 drum/335 lb = 337 drums

42-389 200 RECYCLED WHITE 5 SQUARE Made in U.S.A.

Alternative 5A – UV/OX to 1×10^{-4} risk in 30 yrs   Dec 7, 1993

Alternative 5A assumes the use of UV/oxidation w/ GAC polishing for 30 yrs to remediate the aquifer to 1×10^{-4} risk. The flow rate for this alternative is 78 gpm. The following categories of operating costs are developed below:

- Monitoring
- 5-yr Review
- Metals Precipitation
- Electrical
- Ozone
- GAC
- GAC Incineration
- Disposal

Monitoring – See Costing in Alt. 2

5-yr Review – see Costing in Alt 1

Metal Precipitation – operating cost based on conversations with Andco Environmental Processes and verified based on EPA study for the removal of heavy metals.

Cost for chemicals to treat UMDA ground water was $0.4 /1000 gal

Electrical – Useage was developed based on UV lights, pumps, & misc. electrical for heating building, lighting, ect.

Electrical cost estimate for the UV lights was based on conversations between Kevin Cahill of ADL & Doug Reed of Solar Chem. The Solar Chem electrical estimate was used because it was higher than Ultrox's estimate and was therefore belived to be more conservative.

75 kWh /1000 gal of water treated

$$78\,\text{gal/min} \times \frac{60\,\text{min}}{\text{hr}} \times \frac{24\,\text{hr}}{\text{day}} \times \frac{365\,\text{day}}{\text{yr}} = 40{,}996{,}800\,\text{gal/yr}$$

Alternative 5A (cont.)

Dec 7, 1993

Electrical (cont.)

40,996,800 gal/yr × 75 kWhr/1000 gal = 3.1 M kWhr/yr

an additional 15% of kWhr was added for the pumps and misc. electrical usage.

3.1 M kWhr/yr × 1.15 (for pumps + misc electrical) = 3.6 M kWhr

Ozone - Costs are based on electrical costs of $0.06/kWh and an O_3 dose of 2 mg/l/min. Based on these inputs the Milan report stated an O_3 electrical cost of $0.25/1000 gal

GAC usage - GAC was used w/ UV/ox to polish the ground water stream. Total explosive concentration on GAC was limited to 7% in order to avoid having a reactive material.

Explosive loading to GAC assuming a loading of 10% of the original concentration of 5,400 μg/L

$540\ \mu g/L \times 3.79\ L/gal \times 78\ gal/min \times 525{,}600\ \frac{min}{yr} \times 1g/1\times10^6\ \mu g$

$\times\ 1lb/454g = 184\ lb/yr$

$184\ lb\ explosive/yr \times lb\ GAC/0.07\ lb\ Explosive = 2640\ lb\ GAC/yr$

$2640\ lb\ GAC/yr \times 1\ ton/2000\ lb = 1.3\ tons\ GAC/yr$

Carbon Change out

$365\ days/yr \times 1yr/1.3\ tons\ GAC = 281\ days/ton$

42-399 200 RECYCLED WHITE 5 SQUARE Made in U.S.A.

Alternative 5A (cont.) Dec 7, 1993

GAC Incineration - Spent GAC was calculated in previous calc. quanity of GAC / drum is assumed to be 335 lb/drum

$1.3\ \text{tons/yr} \times 2000\ \text{lb/ton} \times 1\ \text{drum}/335\ \text{lbs} = 7.8\ \text{drums}$

Disposal - This is for the disposal of hydroxide sludges from the metal precipitation unit and a small amount of suspended solids from the extration wells. Solids production is based on conversations with Andco Environmental Processes. (5.2 lb/1000 gal)

$5.2\ \text{lb}/1000\ \text{gal} \times 78\ \text{gal/min} \times 525{,}600\ \frac{\text{min}}{\text{yr}} \times 1\ \text{ton}/2000\ \text{lb}$

$= 107\ \text{tons/yr}$

Alternative 5B assumes the use of UV/oxidation w/ GAC polishing for 10 yrs to remediate the aquifer to 1×10^{-4} risk. The flow rate for this alternative is 200 gpm. The following categories of operating costs are developed below:

- Monitoring
- 5-yr Review
- Metals Precipitation
- Electrical
- Ozone
- GAC
- GAC Incineration
- Disposal

Monitoring - See Costing in Alt. 2

5-yr Review - see Costing in Alt 1

Metal Precipitation - operating cost based on conversations with Andco Environmental Processes and verified based on EPA study for the removal of heavy metals.

Cost for chemicals to treat UMDA ground water was \$0.4 /1000 gal

Electrical - Useage was developed based on UV lights, pumps, & misc. electrical for heating building, lighting, ect.

Electrical cost estimate for the UV lights was based on conversations between Kevin Cahill of ADL & Doug Reed of Solar Chem. The Solar Chem electrical estimate was used because it was higher than Ultrox's estimate and was therefore belived to be more conservative.

75 kWh / 1000 gal of water treated

$$200\ \frac{gal}{min} \times \frac{60\ min}{hr} \times \frac{24\ hr}{day} \times \frac{365\ day}{yr} = 105{,}120{,}000\ gal/yr$$

42-392 100 RECYCLED WHITE 5 SQUARE
42-399 200 RECYCLED WHITE 5 SQUARE
Made in U.S.A.

Electrical (cont.)

105,120,000 gal/yr × 75 kWhr/1000 gal = 7.9 M kWhr/yr

an additional 15% of kWhr was added for the pumps and misc. electrical usage.

7.9 M kWhr/yr × 1.15 (for pumps + misc electrical) = 9.1 M kWhr

Ozone - Costs are based on electrical costs of $0.06/kWh and an O_3 dose of 2 mg/l/min. Based on these inputs the Milan report stated an O_3 electrical cost of $0.25/1000 gal

GAC usage - GAC was used w/ UV/ox to polish the ground water stream. Total explosive concentration on GAC was limited to 7% in order to avoid having a reactive material.

Explosive loading to GAC assuming a loading of 10% of the original concentration of 5,400 µg/L

540 µg/L × 3.79 L/gal × 200 gal/min × 525600 min/yr × 1 g/1×10⁶ µg
× 1 lb/454 g = 474 lb/yr

474 lb explosive/yr × 1 lb GAC/0.07 lb Explosive = 6770 lb GAC/yr

6770 lb GAC/yr × 1 ton/2000 lb = 3.4 tons GAC/yr

Carbon change out

365 days/yr × 1 yr/3.4 tons GAC = 107 days/ton

Alternative 5B (cont.) DEC 7, 1993

GAC Incineration - Spent GAC was calculated in previous calc. quanity of GAC / drum is assumed to be 335 lb/drum

3.4 tons/yr x 2000 lb/ton x 1 drum/335 lbs = 20.3 drums

Disposal - This is for the disposal of hydroxide sludges from the metal precipitation unit and a small amount of suspended solids from the extration wells. Solids production is based on conversations with Andco Environmental Processes. (5.2 lb/1000 gal)

5.2 lb/1000 gal x 200 gal/min x 525,600 $\frac{min}{yr}$ x 1 ton/2000 lb

= 273 tons/yr

Alternative 6A — GAC to 1×10 risk in 30 yrs DEC 7, 1993

Alternative 6A assumes the use of GAC for 30 yrs to remediate the aquifer to 10^{4} risk. The flow Rate for this Alternative is 78 gal/min. The following categories of operating costs are developed below:

- Monitoring
- 5-yr review
- Electrical
- GAC Usage
- GAC Incineration

Monitoring - see costing in Alt. 2

5-yr Review - See costing in Alt 1

Electrical - Electrical usage was developed based on pumps, lighting, and other misc. electrical.

Pumps -

Extraction pumps ~~maximum~~ rating 70 gpm, 2.5 hp motor efficiency of 60%

2.5 hp/0.6 × 3 pumps × 24 hr/day × 365 day/yr × 0.765 kw/hp

= 83,770 kw/yr

Feed pump maximum rating 100 gpm, 2.0 hp efficiency of 60%

2 hp/0.60 × 1 pump × 24 hr/day × 365 day/yr × 0.765 kw/hp

= 22,340 kw/yr

Discharge pump maximum rating 100 gpm, 3 hp motor efficiency of 60%

$3\ hp/0.60 \times 1\ pump \times 24\ hr/day \times 365\ day/yr \times 0.765 \frac{kw}{hp}$

= 33,510 kw/yr

Electrical (cont.)

Total pump electrical usage

$= 83{,}700 \text{ kw/yr} + 22{,}340 \text{ kw/yr} + 33{,}510 \text{ kw/yr}$

$= 139{,}550 \text{ kw/yr}$

Lighting - assume a 10,000 ft^2 building with lighting requirements of 30 ft-candles and a maintenance factor of 0.70.

$$= \frac{10{,}000 \text{ ft}^2 \times 30 \text{ ft-candles}}{50 \text{ lumens/wat } (0.70)} = 8{,}600 \text{ watts}$$

$8.6 \text{ kw} \times 24 \text{ hr/day} \times 365 \text{ days/yr} = 75{,}000 \text{ kw/yr}$

Misc. Electrical - An additional 50% electrical was assumed for other needs offices, outside lighting, ect

$= (139{,}550 \text{ kw/yr} + 75{,}000 \text{ kw/yr}) \times 0.5$

$= 107{,}275 \text{ kw/yr}$

Total electrical is 321,825 kw/yr

GAC Usage - GAC was used to remove all the explosive contamination. Total explosive concentration on GAC was limited to 7% in order to avoid having an explosive material.

Explosive loading to the GAC was assumed to be 5400 μg/L

$5{,}400 \text{ μg/L} \times 3.79 \text{ L/gal} \times 78 \text{ gal/min} \times 525{,}600 \text{ min/yr} \times 1\text{g}/1\times10^{-6} \text{μg}$

$\times \text{ lb}/454\text{g} = 1850 \text{ lb Explosive/yr}$

$1850 \text{ lb explosive/yr} \times \text{lb GAC}/0.07 \text{ lb explosive} = 26{,}430 \text{ lb GAC/yr}$

$$26{,}430 \text{ lb GAC/yr} \times \frac{1 \text{ ton}}{2000 \text{ lb}} = 13.2 \text{ tons}$$

Alternative 6A (cont)   Dec 7, 1993

42-399 200 RECYCLED WHITE 5 SQUARE
Made in U.S.A.

GAC usage (cont)

Carbon changeout

365 days/yr × 1 yr / 13.2 tons GAC = 27.6 days/ton GAC

GAC Incineration - Spent GAC was calculated in previous calc.
quantity of GAC/drum is assumed to be
335 lb/drum

13.2 tons GAC × 2000 lb/ton × 1 drum/335 lb = 79 drums

Alternative 6B - GAC to 10 risk in 10 yr DEC 7, 1993

Alternative 6B assumes the use of GAC for 10 yrs to remediate the aquifer to 10^{-4} risk. The flow Rate for this Alternative is 200 gpm. The following categories of operating costs are developed below:

- Monitoring
- 5-yr review
- Electrical
- GAC Usage
- GAC Incineration

Monitoring - see costing in Alt. 2

5-yr Review - See costing in Alt 1

Electrical - Electrical usage was developed based on pumps, lighting, and other misc. electrical.

Pumps -

Extraction pumps maximum rating 200 gpm, 5 hp motor efficiency of 75%

$5\ \text{hp}/0.75 \times 3\ \text{pumps} \times 24\ \text{hr/day} \times 365\ \text{day/yr} \times 0.765\ \text{kw/hp}$

$= 134{,}030\ \text{kw/yr}$

Feed pump maximum rating 250 gpm, 5 hp efficiency of 75%

$5\ \text{hp}/0.75 \times 1\ \text{pump} \times 24\ \text{hr/day} \times 365\ \text{day/yr} \times 0.765\ \text{kw/hp}$

$= 44{,}675\ \text{kw/yr}$

Discharge pump maximum rating 250 gpm, 7 hp motor efficiency of 75%

$7\ \text{hp}/0.75 \times 1\ \text{pump} \times 24\ \text{hr/day} \times 365\ \text{day/yr} \times 0.765\ \frac{\text{kw}}{\text{hp}}$

$= 62{,}500\ \text{kw/yr}$

Alternative 6B (cont) Dec 7, 1993

42-399 200 RECYCLED WHITE 5 SQUARE
Made in U.S.A.

Electrical (cont.)

Total pump electrical usage

= 134,030 kw/yr + 44,675 kw/yr + 62,500 kw/yr

= 241,205 kw/yr

Lighting - assume a 10,000 ft^2 building with lighting requirements of 30 ft-candles and a maintenance factor of 0.70.

$$= \frac{10,000\ ft^2 \times 30\ ft\text{-candles}}{50\ lumens/wat\ (0.70)} = 8,600\ watts$$

8.6 kw × 24 hr/day × 365 days/yr = 75,000 kw/yr

Misc. Electrical - An additional 50% electrical was assumed for other needs offices, outside lighting, ect

= (241,205 kw/yr + 75,000 kw/yr) × 0.5

= 158,100 kw/yr

Total electrical is 474,305 kw/yr

GAC Usage - GAC was used to remove all the explosive contamination. Total explosive concentration on GAC was limited to 7% in order to avoid having an explosive material.

Explosive loading to the GAC was assumed to be 5400 $\mu g/L$

5,400 $\mu g/L$ × 3.79 L/gal × 200 gal/min × 52 ,600 min/yr × $1g/1\times10^6\ \mu g$

× lb/454g = 4740 lb Explosive/yr

4740 lb explosive/yr × lb GAC/0.07 lb explosive = 67,715 lb GAC/yr

$$67,715\ lb\ GAC/yr \times \frac{1\ ton}{2000\ lb} = 33.9\ tons$$

Alternative 6B (cont) Dec 7, 1993

GAC usage (cont)

Carbon changeout

365 days/yr × 1 yr / 33.9 tons GAC = 10.8 days/ton GAC

GAC Incineration - Spent GAC was calculated in previous calc. quantity of GAC/drum is assumed to be 335 lb/drum

33.9 tons GAC × 2000 lb/ton × 1 drum/335 lb = 202 drums

42-399 200 RECYCLED WHITE 5 SQUARE
Made in U.S.A.